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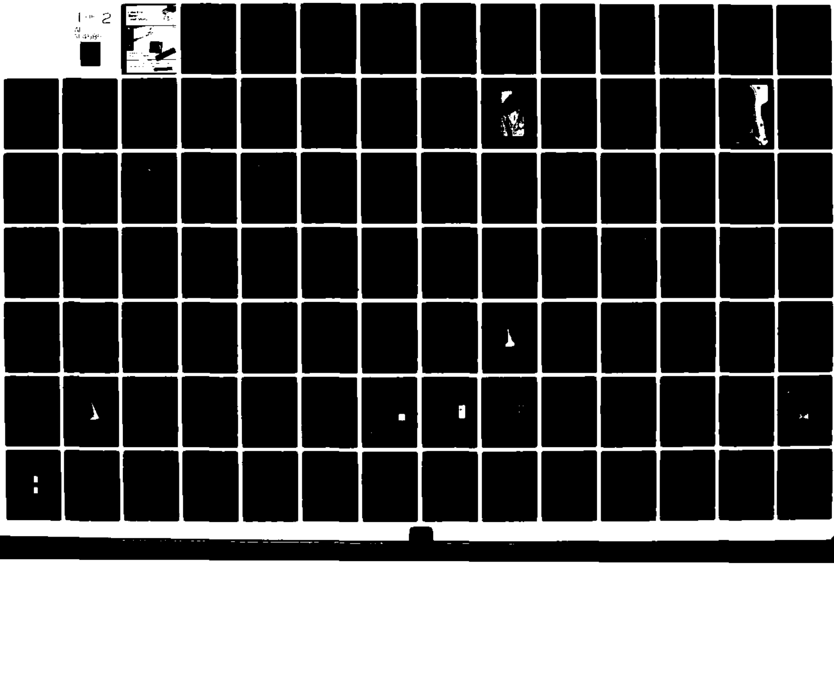

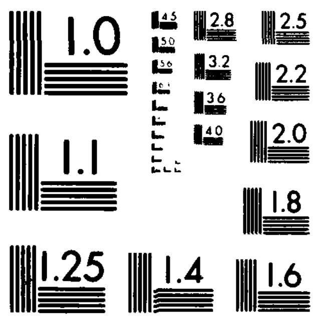

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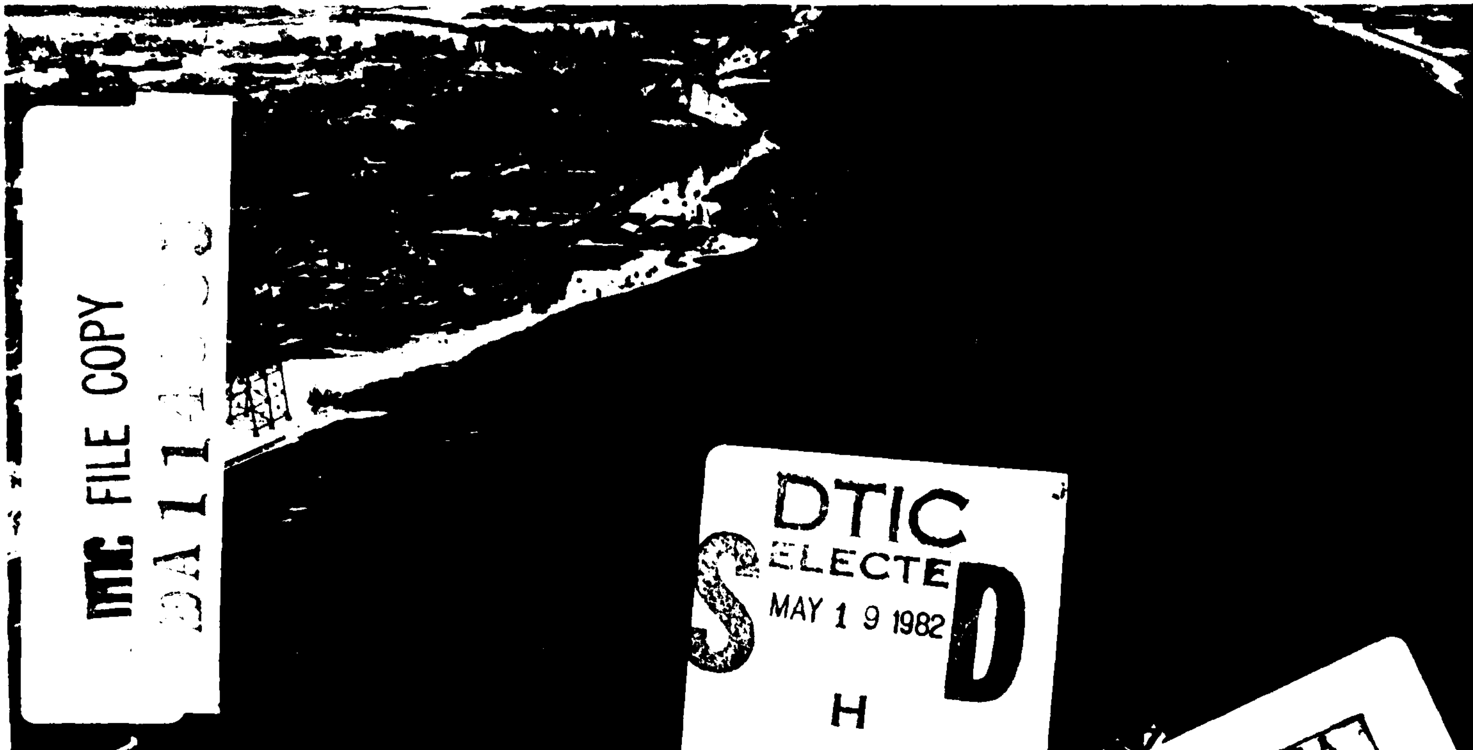

Appendix B
Regulatory Works

International Lake Erie Regulation Study Board
International Joint Commission
July 1981

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The Regulatory Works Appendix describes the engineering works that would be necessary to accomplish limited regulation of Lake Erie. It also describes the remedial works that would be required in the St. Lawrence River to accommodate combined regulation plans for Lakes Erie and Ontario. Plans for limited regulation of Lake Erie are described in the International Lake Erie Regulation Study Board's Main Report and Appendix A, Regulation, both dated July 1981.

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outlet

20. Limited regulation of Lake Erie would require dredging of its outlet river so that greater flows could be released at times when high supplies to the upper Great Lakes occur, and a control structure capable of restoring the preproject outflow condition when supplies are below average. This appendix describes the existing facilities in the outlet of the Lake Erie, and discusses the problems encounted in providing such structures. It also outlines several Niagara regulatory works alternatives, describes the design criteria, and the methods used in preparing preliminary designs and cost estimates.

APPENDIX B

REGULATORY WORKS

LAKE ERIE REGULATION STUDY

REPORT

TO THE

INTERNATIONAL JOINT COMMISSION

BY THE

INTERNATIONAL LAKE ERIE REGULATION

STUDY BOARD

(UNDER THE REFERENCE OF 21 FEBRUARY 1977)

JULY 1981

SYNOPSIS

The Regulatory Works Appendix describes the engineering works that would be necessary to accomplish limited regulation of Lake Erie. It also describes the remedial works that would be required in the St. Lawrence River to accommodate combined regulation plans for Lakes Erie and Ontario. Plans for limited regulation of Lake Erie are described in the International Lake Erie Regulation Study Board's main report and Appendix A - Lake Regulation.

Limited regulation of Lake Erie would require dredging of its outlet river so that greater flows could be released at times when high supplies to the upper Great Lakes occur, and a control structure capable of restoring the preproject outflow condition when supplies are below average. This appendix describes the existing facilities in the outlet of the Lake Erie, and discusses the problems encountered in providing such structures. It also outlines several Niagara regulatory works alternatives, describes the design criteria, and the methods used in preparing preliminary designs and cost estimates.

The various regulation plans developed for Lake Erie require various increases in outlet capacity. In order to implement these regulation plans, the Board examined seven different Niagara alternative structures. These structures would have capacities ranging from 4,000 cubic feet per second, such as the case of the modified Black Rock Navigation Lock, to about 30,000 cfs, such as the case of the partial Niagara River structure.

From a series of Lake Erie regulation plans, the Board selected three for more detailed evaluation. These are Plans 6L, 15S, and 25N. Plan 6L would require the use of the Black Rock Navigation Lock modified to permit year-round operation. The average annual costs and their cost in equivalent present worth, are $1.2 million and $13.8 million, respectively. Plan 15S would require the construction of a Squaw Island diversion channel. The average annual costs and their cost in equivalent present worth, are $2.0 million and $22.5 million, respectively. Plans 25N would require channel enlargement in the Niagara River, and construction of a structure extending part way from the shore into the Niagara River. The average annual costs and their cost in equivalent present worth, are $11.6 million and $134.3 million. All cost figures are at July 1979 price level.

Limited regulation of Lake Erie would change the sequence and magnitude of supplies to Lake Ontario. Noting that the St. Lawrence Seaway and Power Project could not cope with the record high water supplies to Lake Ontario in the early 1970's, the Board estimated the locations and extents of channel enlargements that would be required in the St. Lawrence River. Such channel enlargements would provide the additional capacities so that, when tested over the study period 1900-1976, the resulting levels and outflows of Lake Ontario would satisfy the International Joint Comission's Orders of Approval for the regulation of Lake Ontario.

To provide the capacities solely to accommodate the high supplies of the early 1970's, channel enlargements in the International and Canadian Reaches of the St. Lawrence River would be required. The average annual costs and

their cost in equivalent present worth, are $6.9 million and $80.1 million, respectively. No additional channel enlargement would be required for Plan 6L. To accommodate Plan 15S, the average annual costs of the channel enlargement in the St. Lawrence River, and their cost in present worth, are $8.3 million and $96.7 million, respectively. To accommodate Plan 25N, the average annual costs of the channel enlargement in the St. Lawrence River and their cost in present worth, are $7.4 million and $85.6 million, respectively.

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Section 1

INTRODUCTION

1.1 General

As a result of a recommendation in the International Joint Commission's 1976 Report to the Governments of Canada and the United States, entitled "Further Regulation of the Great Lakes," the Governments issued on February 21, 1977 a reference to the International Joint Commission (IJC). Pursuant to this reference, the Commission established the International Lake Erie Regulation Study Board. The Commission directed the Board to undertake a study to determine possibilities for lowering extremely high water levels by limited regulation of Lake Erie, taking into account the applicable Orders of Approval of the Commission and the recommendations of the Canada-Quebec study of flow regulation in the Montreal region. As part of the study, the Board examined a broad spectrum of regulation-related economic, social, and environmental effects of limited regulation throughout the Great Lakes Basin, including the International and Canadian Reaches of the St. Lawrence River. Any modification to the outflows of Lake Erie would affect a portion of the supply of water to Lake Ontario and, to some extent, affect the levels and outflows of the upper Great Lakes. In this regard, the Board evaluated three regulation categories for study purposes. Categories 1 and 2 consider Lake Erie regulation constrained by the present Orders of Approval and channel limitations of the St. Lawrence River. Category 3 considers channel modifications and/or remedial measures in the St. Lawrence River to accommodate regulation of Lakes Erie and Ontario. A more detailed description of the three regulation categories is presented in Appendix A, Lake Regulation. The Commission further directed that if the Board finds that new or altered regulatory works or other measures would be practical, it should estimate their costs, and the effects, whether beneficial or adverse, on the various interests. Moreover, the cost and effects of remedial works needed to compensate for any adverse effects resulting from such regulatory works should also be examined. In this regard, the Board studied the remedial works that would be necessary in the St. Lawrence River to accommodate increased flows resulting from limited regulation of Lake Erie under Category 3.

Limited regulation of Lake Erie requires up to three basic engineering alterations: first, channel enlargements are required to increase the discharge capacity of the Niagara River outlet so that, when necessary, more water could be released than under unregulated conditions; second, a control structure is needed to decrease the outflow to restore preproject conditions during periods of low and average lake levels; and, third, channel enlargements are necessary to increase the discharge capacity of the St. Lawrence River so as to meet the requirements for the regulation of Lake Ontario. The channel enlargements, new structures, and appurtenant works considered necessary to accomplish limited regulation of Lake Erie are the subject of this Appendix.

1.2 Purpose

The purpose of this Appendix is to describe the outlet systems of Lake Erie and Lake Ontario, the problems to be faced in providing the required regulatory and remedial facilities, the design criteria and methods used, and the preliminary designs and cost estimates of the engineering works which would be required to institute the various regulation plans considered in this study.

1.3 Scope

To provide limited regulation of Lake Erie under Categories 1 and 2, a control structure and/or channel enlargement would be required at the head of the Niagara River. Section 2 of this Appendix deals with the Niagara River system and discusses the various regulatory works alternatives that were considered in the study process. The St. Lawrence River system is the subject of Section 3. Limited regulation of Lake Erie would result in an increase in the frequency and duration of high Lake Ontario outflows and would require an increase in the discharge capacity of the St. Lawrence River under Category 3. To provide the necessary discharge capacity, channel enlargements would be required in certain sections of the International Reach of the river. In addition, channel enlargements would also be required in the Lachine Rapids section of the Canadian Reach to mitigate flooding in Lake St. Louis area. The designs and cost estimates for each regulatory works alternative are included in Sections 2 and 3 along with cost estimates for the various selected regulation plans.

Throughout the course of these studies, a number of reports were prepared by various governmental agencies and private consulting engineering firms from which appropriate material was drawn for the purpose of the preliminary design of regulatory works. A reference list is included in Annex C.

All data which were used during the course of these regulatory works studies, including contributory reports, are filed in a central location in Canada and the United States. These data may be obtained at either of the following agencies:

Water Planning and Management Branch
Inland Waters Directorate
Environment Canada
P.O. Box 5050
Burlington, Ontario Canada L7R4A6

Buffalo District
U. S. Army Corps of Engineers
1776 Niagara Street
Buffalo, New York, U. S. A. 14207

1.4 Study Organization

The Working Committee, established by the Lake Erie Regulation Study Board, created a Regulatory Works Subcommittee to conduct the necessary engineering studies and to prepare designs and cost estimates of the works which

would be required to implement the selected regulations plans. The terms of reference of the subcommittee are reproduced as Annex A. The subcommittee was comprised of personnel from the U. S. Army Corps of Engineers, Power Authority of State of New York, New York State Department of Environmental Conservation, St. Lawrence Seaway Development Corporation, Canadian Department of Environment, Canadian Department of Public Works and Ontario Hydro. The members of this subcommittee are listed in Annex B.

1.5 Prior Studies

The most significant relevant prior studies were conducted by the International Great Lakes Levels Board and the U. S. Army Corps of Engineers. The findings of the Levels Board were published in a report dated December 1973, entitled "Regulation of Great Lakes Water Levels, Report to the International Joint Commission." Appendix G of that report describes the engineering works that would be necessary to accomplish further regulation of the levels and flows of the Great Lakes. In particular, Section 4 of Appendix G describes two alternatives for Niagara River control structures and channel enlargement to either increase or decrease the levels and flows of Lake Erie. Section 4 also provides a preliminary appraisal of a plan for increasing Lake Erie outflow via the Black Rock Canal and a diversion channel/control structure to be located on Squaw Island. The findings of the Corps of Engineers were published in a report dated September 1974, entitled "Report on Superior-Erie-Ontario Regulation Plan, SEO-17P." The letter report focused on plans for the limited regulation of Lake Erie and was an extension of the Squaw Island diversion channel study documented in the 1973 Levels Board Report discussed above. For the present study, a wide range of alternative plans were developed and optimized utilizing different types and locations of structures.

The subcommittee has also, wherever appropriate, referred to and drawn upon information given in reports of other IJC studies and the results of various independent studies.

Section 2

NIAGARA RIVER SYSTEM

2.1 Preface

An array of structural alternatives in the Niagara River was chosen to accommodate a wide range of flows permitting limited regulation of Lake Erie associated with the three regulation categories selected for study purposes and discussed in Section 1.1. Preliminary engineering designs and cost estimates for regulatory works in the Niagara River were prepared to: (1) facilitate site selection; (2) provide a range of discharge capacity versus cost curves to be used as input during the formulation of regulation plans; and (3) form a basis for the evaluation of the selected regulation plans presented in Appendix A, Lake Regulation. The following is a detailed summary of the studies completed and preliminary results.

2.2 Description of the Project Area

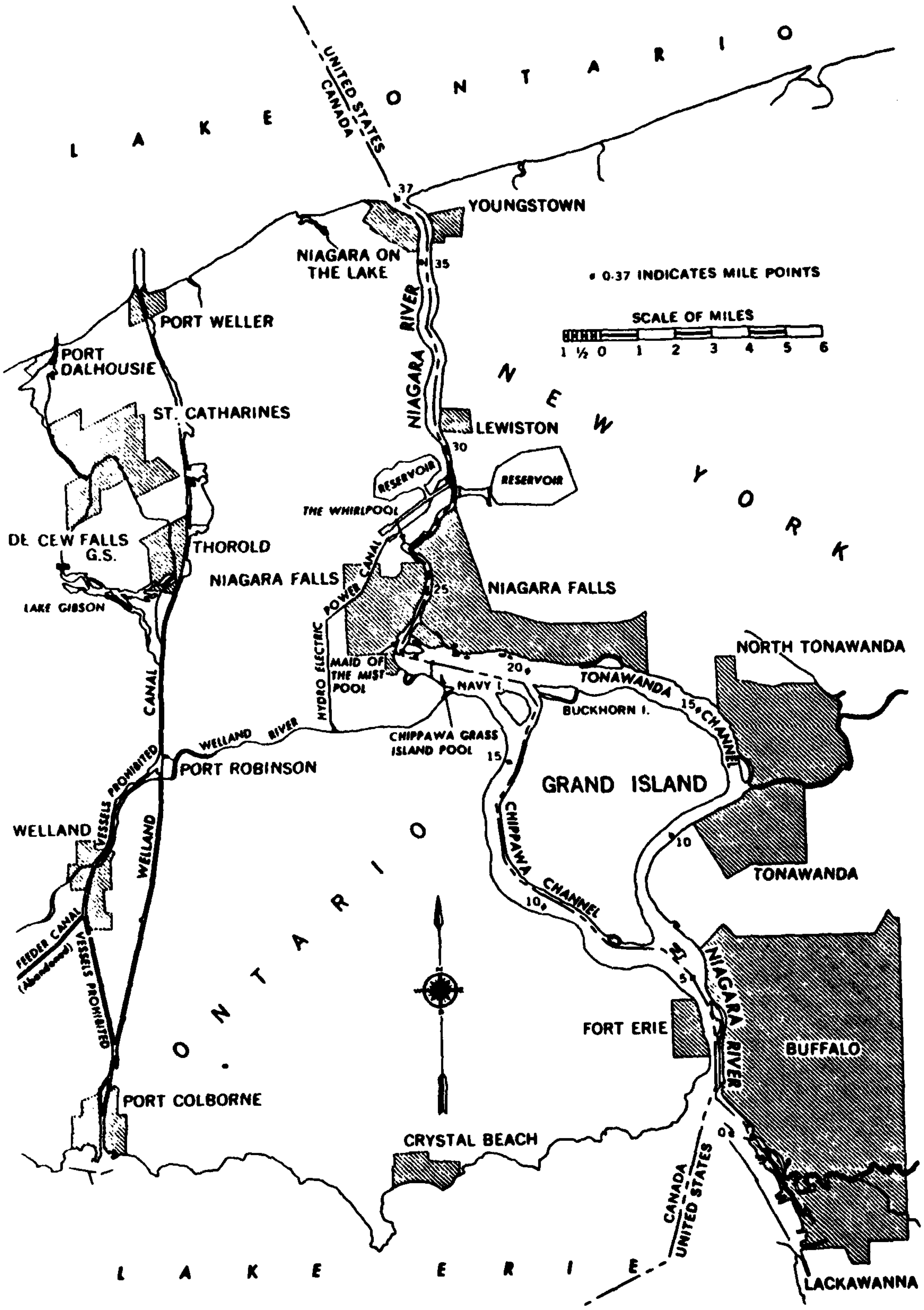
The Niagara River, about 35 miles in length, links Lake Erie at Buffalo, New York, and Lake Ontario at Niagara-on-the-Lake, Ontario. The average fall over its course is 325 feet, about half of which is concentrated at Niagara Falls, located approximately 22 miles below the head of the river. Over the period 1900-1976, the monthly mean Niagara River discharge has varied from 265,000 cfs to 116,000 cfs and has averaged about 200,000 cfs. A portion of the Lake Erie outflow is also diverted through the Welland Canal.

2.2.1 General

An outstanding physical characteristic of the Niagara River is the rapid change in the water surface profile between various points on the river system. The Niagara River may be considered to consist of three major reaches: the Upper Niagara River; the Niagara Cascades and Falls; and, the Lower Niagara River which extends from the foot of the Falls at the Maid-of-the Mist Pool to Lake Ontario. A location map of the Niagara River and surrounding area is shown on Figure B-1.

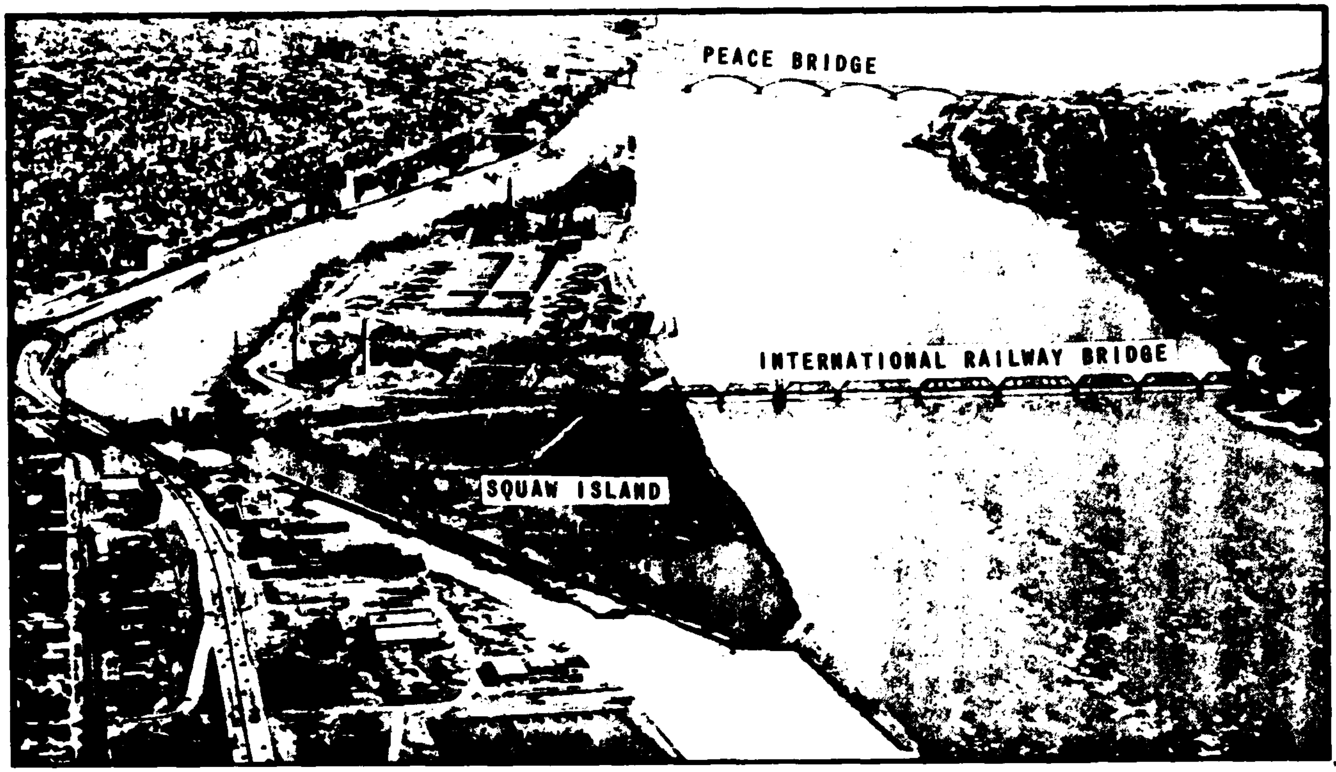
The Upper Niagara River, which extends from Lake Erie below Buffalo Harbor to the Cascades and Niagara Falls, is of primary interest since regulatory works must be located in the upper portion of this reach to fulfill the study objectives. An aerial photograph of the reach, extending from the Peace Bridge to the downstream extremity of Squaw Island is shown on Figure B-2.

From Lake Erie to Strawberry Island, a distance of approximately 5 miles, the channel width varies from 9,000 feet at its funnel-shaped entrance to 1,500 feet at Squaw Island below the Peace Bridge. The fall over this upper 5-mile portion is 6.1 feet. In the upper 2 miles of the river, the maximum depth is approximately 20 feet with velocities as high as 12 fps in the vicinity of the Peace Bridge. This part of the river is paralleled by the Black Rock Canal. Below Squaw Island, the river widens to approximately 2,000 feet and becomes more placid with velocities of 4 to 5 feet per second.



NIAGARA RIVER - LOCATION MAP

FIGURE B-1



(COURTESY CANADIAN DEPARTMENT OF ENVIRONMENT)

AERIAL PHOTOGRAPH OF UPPER NIAGARA RIVER LOOKING UPSTREAM TOWARDS SQUAW ISLAND.

FIGURE B-2

The Upper Niagara River is suitable for recreational boating. Downstream from Navy Island, boating is discouraged due to the danger of being swept over Niagara Falls.

At Strawberry and Grand Islands, the river is divided into two channels, the Chippawa Channel and the Tonawanda Channel. The Chippawa Channel is approximately 11 miles in length and varies from 2,000 to 4,000 feet in width. Velocities range from 2 to 3 fps. The Chippawa Channel carries approximately 60 percent of the total river flow. The Tonawanda Channel is approximately 15 miles long and varies from 1,500 to 2,000 feet in width above Tonawanda Island. Downstream thereof, the channel varies from 1,500 to 4,000 feet in width. Velocities range from 2 to 3 fps. The islands of Navy and Tonawanda are located in the Chippawa and Tonawanda Channels, respectively.

At the foot (north) of Grand Island, the channels unite to form the 3-mile-long Chippawa-Grass Island Pool which leads to a partial control structure extending from the Canadian shoreline. This structure is located approximately 4,500 feet upstream of the Falls. The fall from Lake Erie to the Chippawa-Grass Island Pool control structure is about 10 feet.

The immediate project area extends from Lake Erie below Buffalo Harbor to the downstream extremity of Squaw Island, a distance of approximately 3-1/2 miles.

2.2.2 Existing Regulatory Works

To fulfill the objectives of the 1950 Niagara Diversion Treaty, a control structure was constructed in the lower end of the Chippawa-Grass Island Pool approximately 4,500 feet upstream of the Falls. The control structure permits the diversion of water to the Sir Adam Beck and Robert Moses high-head power plants and the maintenance of the minimum flows required by the Treaty over the Falls. The original structure, as constructed between 1954 and 1957, consists of thirteen 100-foot gates for a total length of 1,500 feet. Following completion of power facilities expansion in 1961, five additional 100-foot gates were constructed between 1961 and 1963. A man-made island, called Tower Island, was constructed at the end of the structure.

The control structure is operated by the Power Entities to maintain flows of not less than 100,000 cfs over the Falls during the daylight hours of the tourist season and not less than 50,000 cfs at other times. The directives of the International Niagara Board of Control, dated 30 June 1955 and 27 February 1973, require the entities to operate the control structure such that the levels of Chippawa-Grass Island Pool are maintained as near as practicable to its long-term mean natural level of 561.0 feet (IGLD) as recorded at Material Dock gauge. The effect of this control structure does not extend far enough upstream to alter the natural outflow of Lake Erie into the Niagara River.

2.2.3 Power Facilities and Flows

All power diversions are made in compliance with the 1950 Niagara Diversion Treaty so that the criteria as outlined in paragraph 2.2.2 above are met. A description of the plants and the corresponding diversions are discussed in Appendix E, Power.

2.2.4 Navigation Facilities

The Black Rock Canal parallels the upper reach of the Niagara River from Buffalo Harbor to the downstream end of Squaw Island, from which point a navigation channel in the river extends to Tonawanda, New York. The canal and navigation channel have a depth of about 21 feet. The canal provides an alternate route around the constricted, shallow, and high velocity Peace Bridge reach at the head of Niagara River. Extending from Buffalo Harbor to the river above Strawberry Island, the canal is separated from the river by a series of stone and concrete walls and by Squaw Island. The Black Rock Lock, which has a lift of about 5 feet, is located near the lower end of the canal. Operation of the lock requires the equivalent of a flow of about 10 cfs. From Tonawanda to Niagara Falls, New York, opposite the southern tip of Grand Island, a navigation channel with a minimum depth of 12 feet below low water datum is maintained.

A further discussion of navigation facilities and the effects of limited regulation of Lake Erie on commercial navigation can be found in Appendix C, Commercial Navigation.

2.2.5 Bridges, Docks, and Other Facilities

Two bridges linking the Province of Ontario and the State of New York are located over the Upper Niagara River. The Peace Bridge (highway) crosses the head of the river and the Black Rock Canal near Lake Erie. The International Railroad bridge crosses the river and the canal about 1.5 miles downstream from the Peace Bridge. The South and North Grand Island highway bridges traverse the Tonawanda Channel at Kenmore and Niagara Falls, New York, respectively.

Docks for recreational craft are located at many points along the Upper Niagara River with a particularly high concentration along Grand Island. There are commercial docks for bulk commodities along the United States shoreline between the lower end of Black Rock Canal and North Tonawanda, New York.

Several municipal and industrial water intakes and waste outfalls are located in the upper river. Some of these have structures extending above the water surface. The Buffalo sewage treatment plant is located on the upper end of Squaw Island between the Black Rock Canal and the river.

2.3 Selection of Regulatory Works Alternatives

To provide for limited regulation of Lake Erie during periods of high supply, an array of seven structural alternatives were chosen to accommodate

a wide range of increased flows from Lake Erie. The locations of the seven alternatives are shown on Figure B-3. These alternatives are grouped into three types and involve the following:

1. Series "N" - Construction of a partial control structure located in the Niagara River along with compensating dredging;

2. Series "S" - Construction of a control structure and diversion channel across Squaw Island;

3. Series "L" - Modification of the existing Black Rock Lock to permit diversion flow through the open lock chamber.

After reviewing the seven possible alternatives, preliminary designs and cost estimates were prepared for regulatory works involving five of these seven alternatives; namely L1, S1, S2, S3, and N3 (Figure B-3). Preliminary hydraulic investigations of the Niagara River alternatives indicated that N1 and N2 were the least economical of the river plans and were eliminated from further consideration. Alternative N3 was selected as the most feasible N type option. The rationale for selection of alternative N3 is contained in Annex D.

The three types of regulatory works alternatives under consideration are discussed briefly below. A detailed description of each alternative is included in Section 2.6.

2.3.1 Niagara River Alternatives

In the Niagara River, alternatives N1 and N2 would require multi-gated control structures located at sites previously selected and described in the Levels Board 1973 Report. Alternative N3 would require a multi-gated structure located in the river approximately 300 feet downstream from the existing Peace Bridge. Each of the alternatives would also require extensive cofferdams during construction and substantial amounts of rock dredging within the river channel. Size variations of the series "N" alternatives would increase the river's annual discharge capacity up to 29,000 cfs and would cost up to $129.6 million.

Figure B-4 is a location map of alternative N3 which is typical of the series "N" alternatives.

2.3.2 Black Rock Canal - Squaw Island Alternatives

On Squaw Island, alternative S1 would require a diversion channel and control structure located along an alignment selected by the Levels Board and described in their December 1973 report. Alternative S2 would require a diversion channel and control structure located along an alignment parallel to and adjacent to the existing Black Rock Lock. Alternative S3 would require a control structure located along the existing alignment of the Bird Island Pier at the upstream end of Squaw Island. Each of the Squaw Island alternatives also require varying amounts of bank protection at critical locations along the Black Rock Canal. Likewise, the net annual discharge

NIAGARA RIVER REGULATORY WORKS ALTERNATIVES

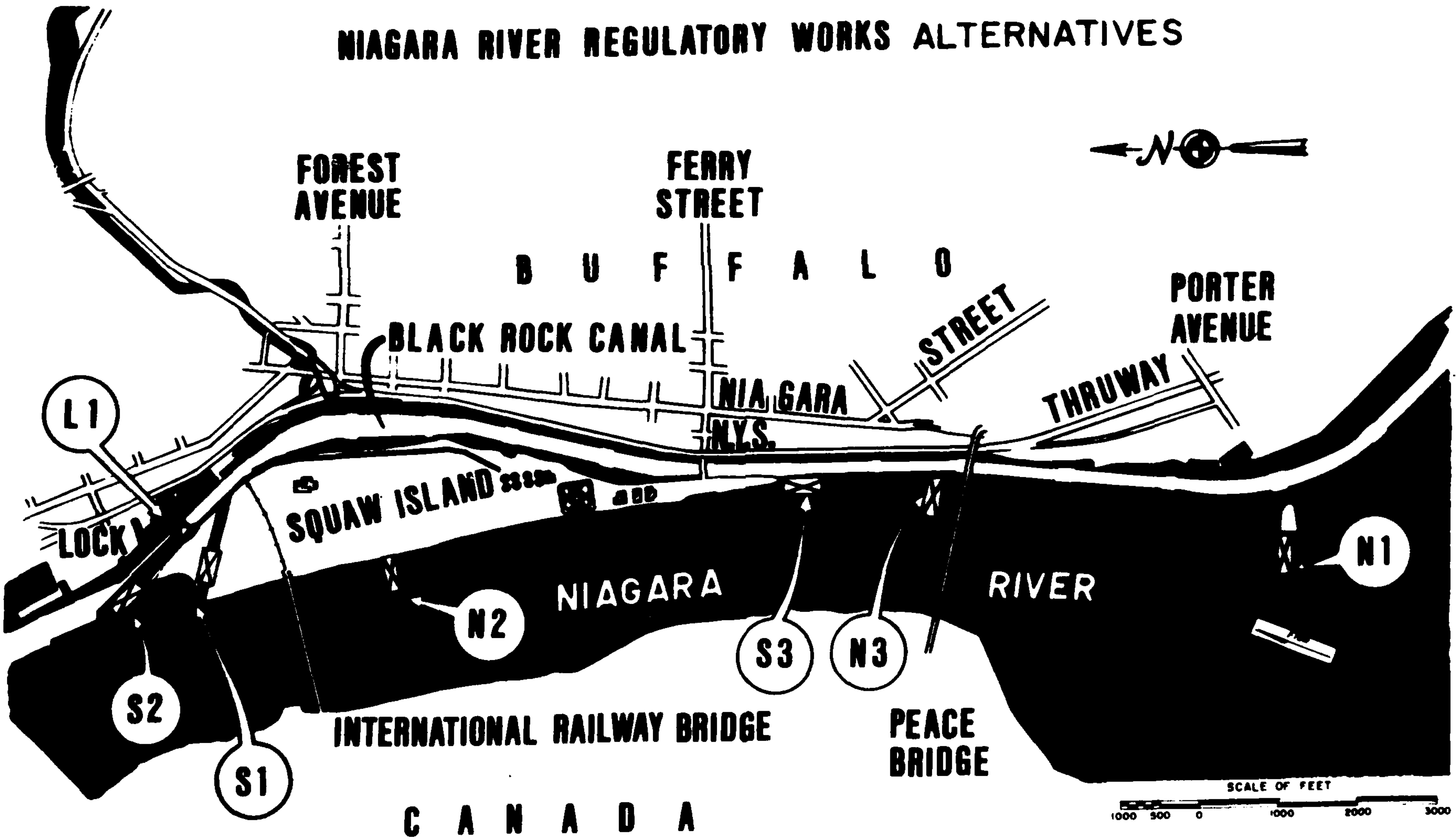
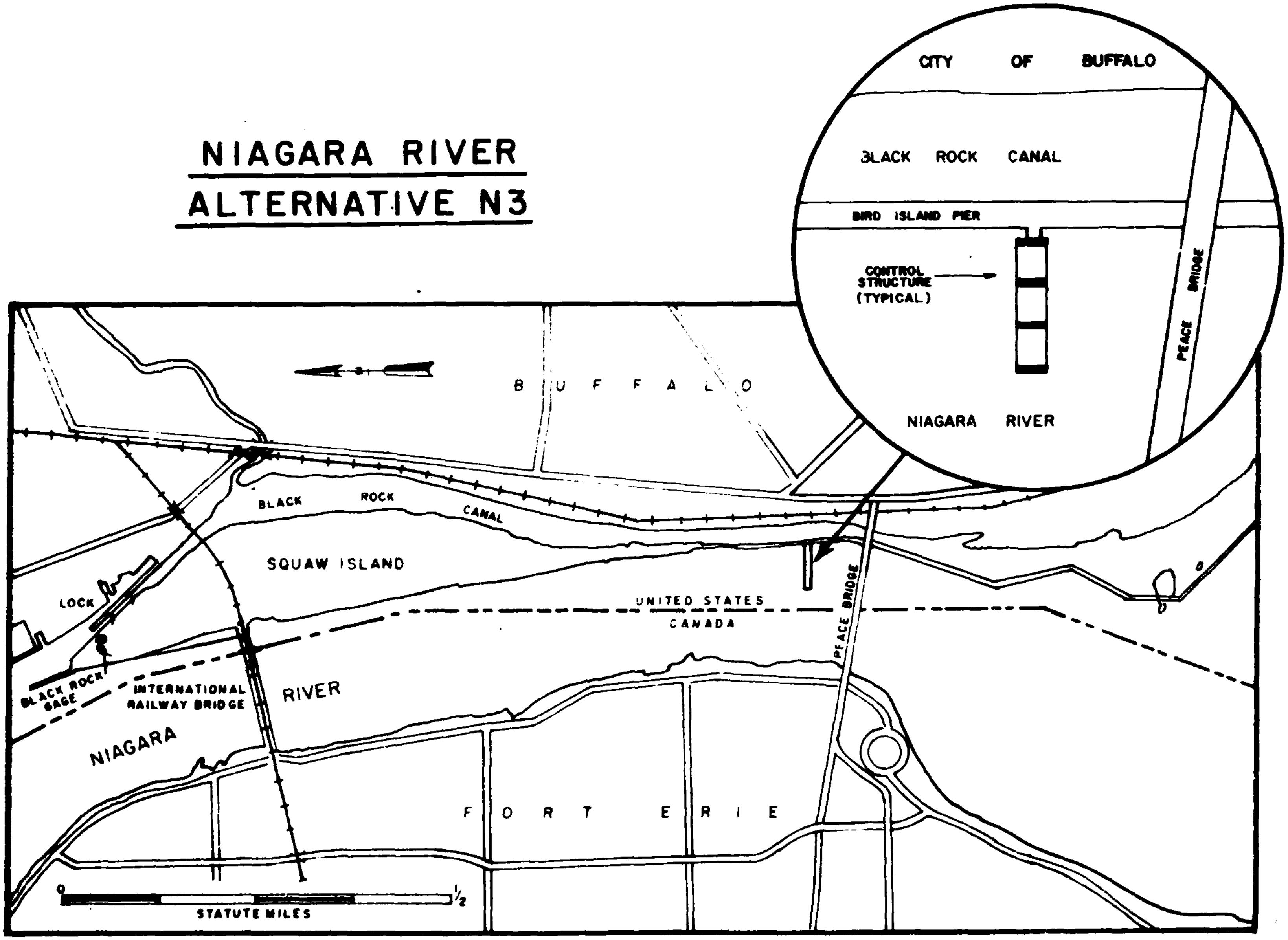


FIGURE B-3

NIAGARA RIVER ALTERNATIVE N3



LOCATION MAP

FIGURE B-4

capacity of each alternative would be substantially limited by seasonal navigation requirements in the canal. In addition, alternatives S1 and S2 would require substantial expenditures for real estate since they would be located on land owned by the city of Buffalo. Size variations of the series "S" alternatives would increase the net annual discharge capacity of the Niagara River up to 12,000 cfs and would cost up to $32.0 million.

Location maps of the series "S" alternatives are shown on Figures B-5, B-6, and B-7.

2.3.3 Black Rock Canal - Black Rock Lock Alternatives

Alternative L1 would require modifying the existing Black Rock Lock by the addition of a pair of sector gates. Since dimensional modification of the lock chamber is not permissible, the maximum discharge capacity of this alternative is limited. This alternative would also require bank protection at critical locations along the Black Rock Canal to achieve mid-range through maximum discharge capacity. In addition, operation of the lock to accommodate seasonal navigation requirements in the Black Rock Canal would substantially limit the net annual discharge capacity of this alternative. Variations of alternative L1 would increase the net annual discharge capacity of Niagara River up to 9,000 cfs and would cost up to $13.1 million.

Figure B-8 is a location map of alternative L1 which is typical of the series "L" alternatives.

2.4 Hydraulic Considerations

The principal hydraulic considerations utilized in studies of Lake Erie regulatory works are discussed below.

2.4.1 Assumptions

Basic assumptions made in the study process were:

1. Uniform hydraulic conditions for Lake Erie will be adopted in order to permit the hydrologic comparison of various regulation plans on a consistent basis;

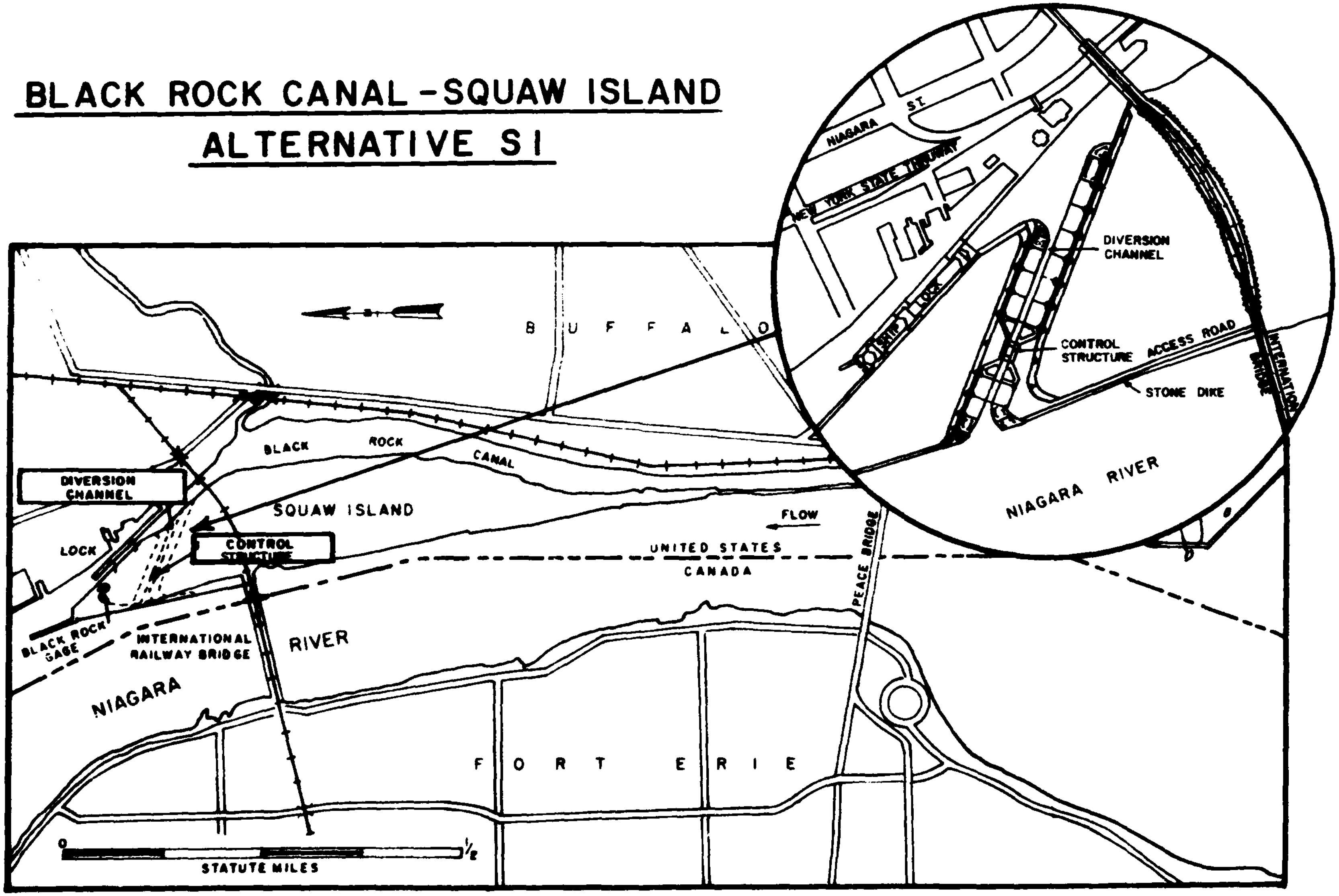
2. The level of Chippawa-Grass Island Pool will be maintained in accordance with the current operating procedures directed by the International Niagara Board of Control, as detailed in its order of 27 February 1973;

3. Flow diversions through the Welland Canal will not change;

4. The Niagara River Ice Boom will be kept in operation;

5. Diversion flows associated with alternatives utilizing the Black Rock Canal will be subject to operational constraints to accommodate both commercial and recreational navigation.

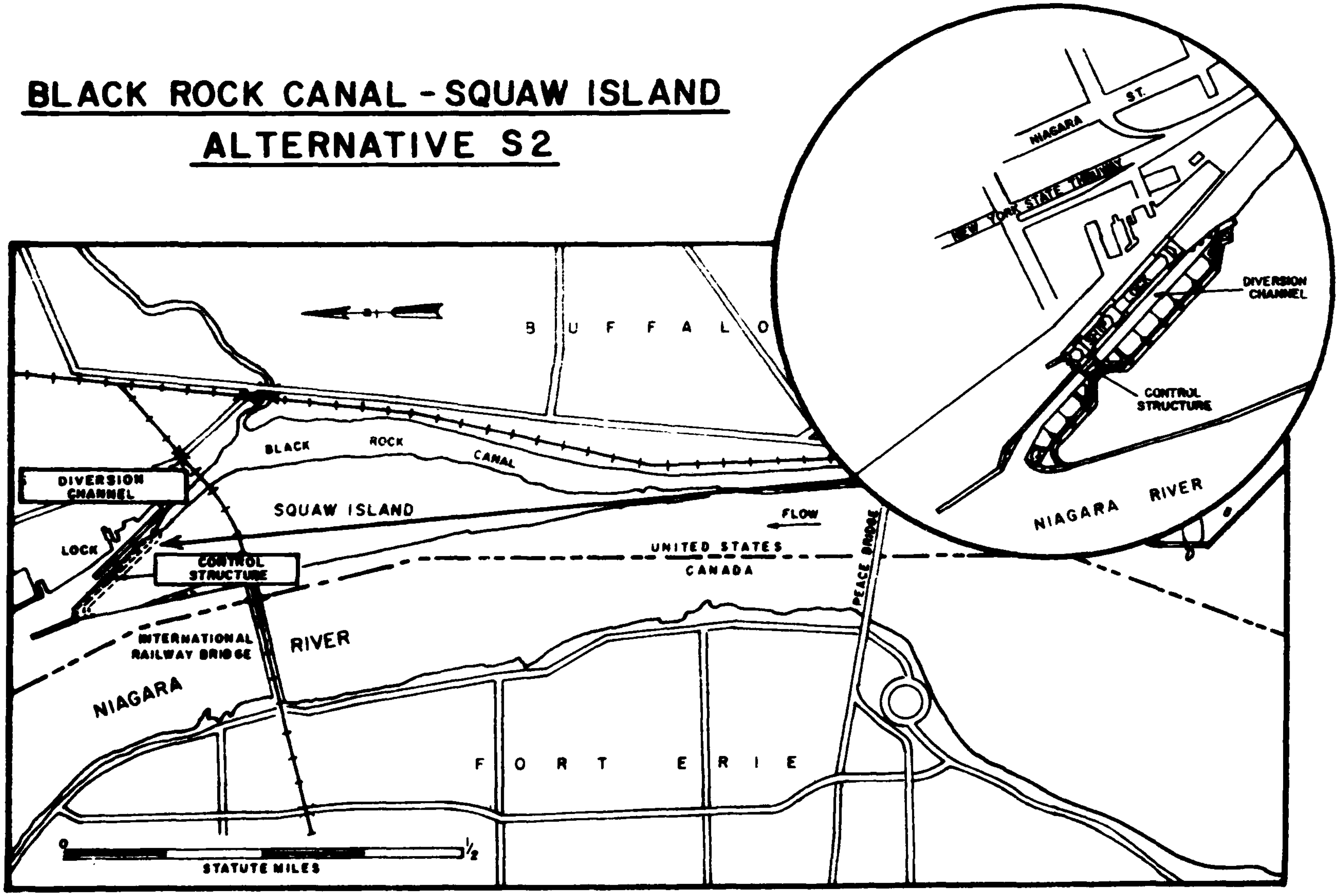
BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE S1



LOCATION MAP

FIGURE B-5

BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE S2



LOCATION MAP

FIGURE B-6

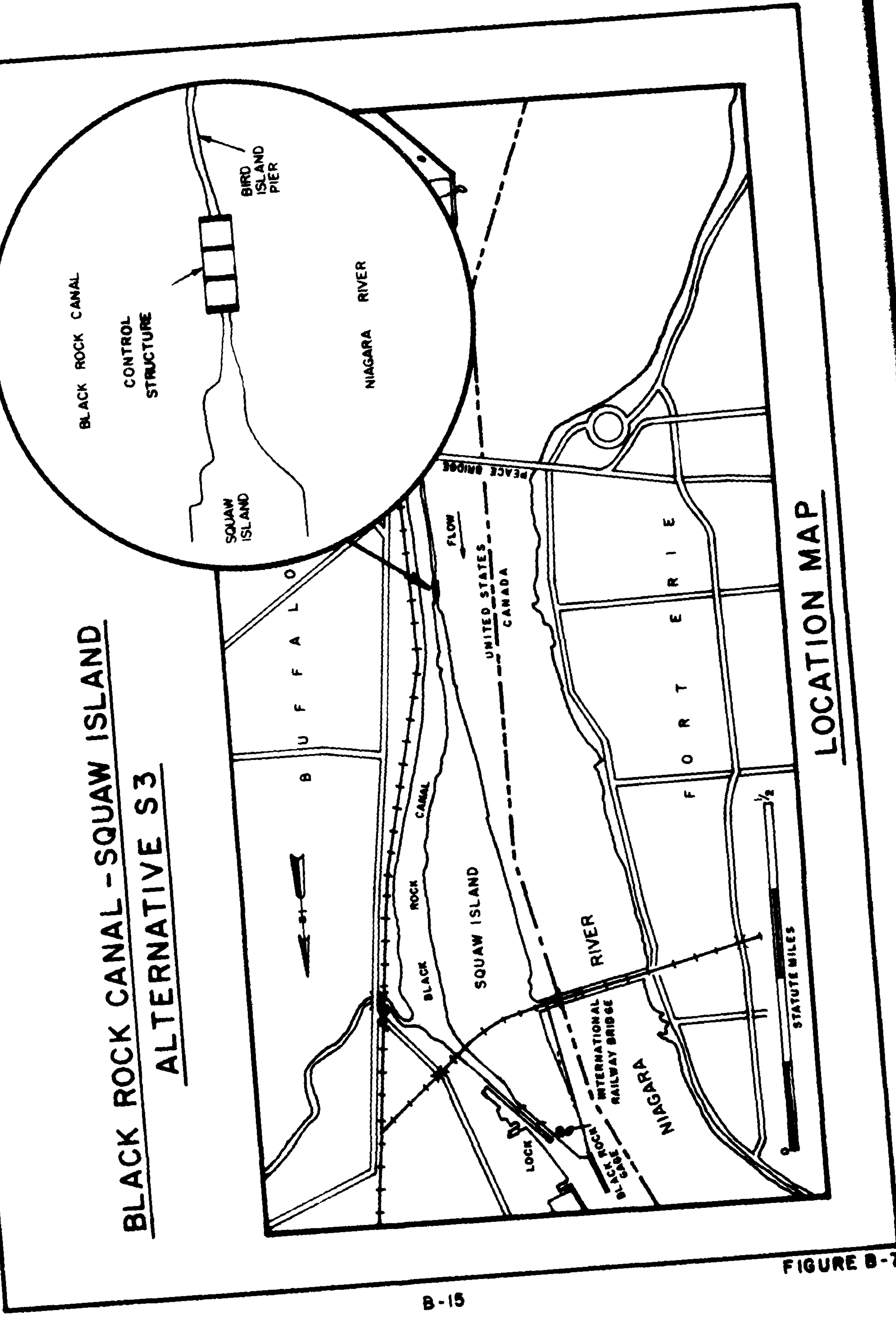
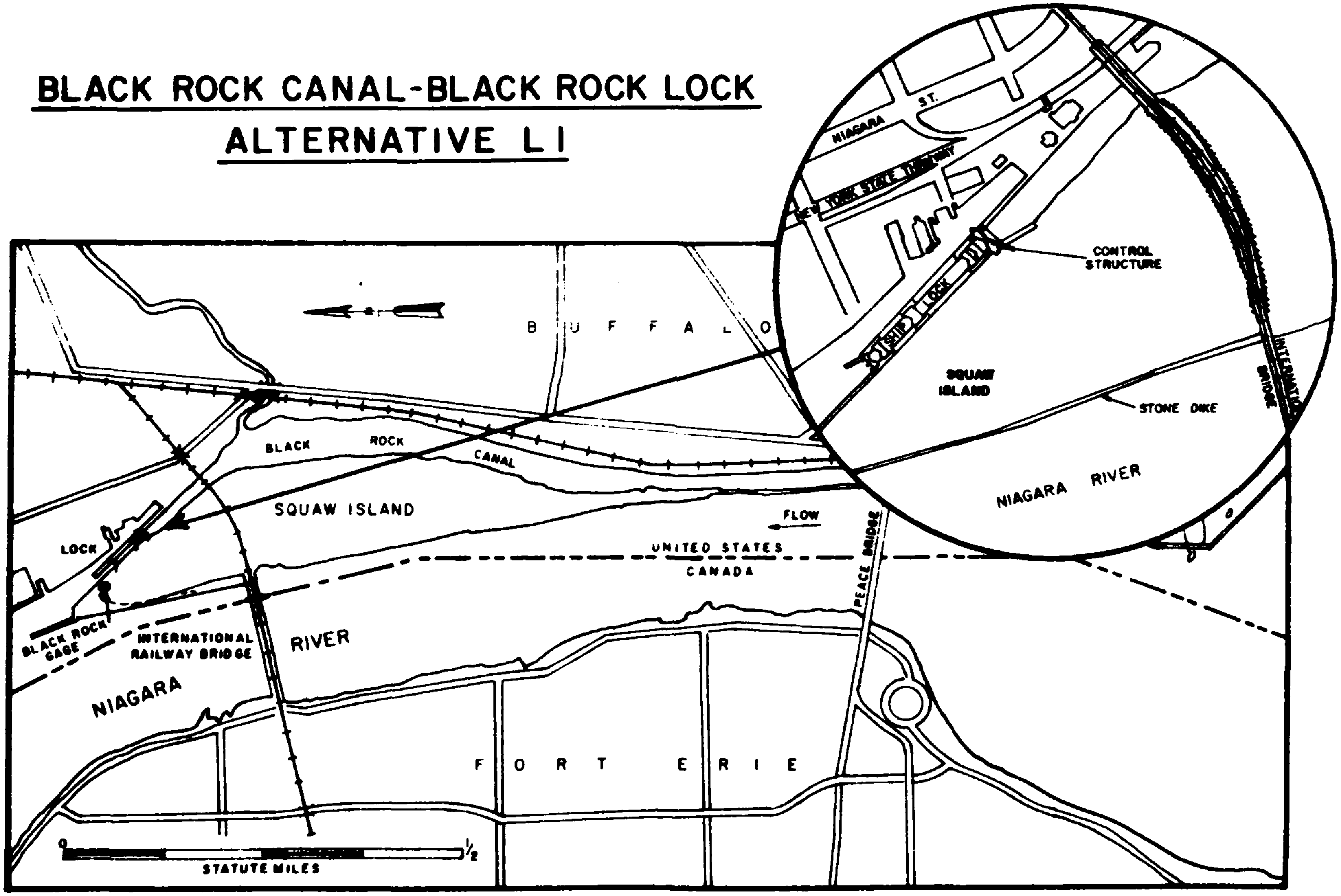

BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE S3
LOCATION MAP
BLACK ROCK CANAL
CONTROL STRUCTURE
NIAGARA RIVER
BIRD ISLAND PIER
SQUAW ISLAND
PEACE BRIDGE
FLOW
UNITED STATES
CANADA
B U F F A L O
F O R T E R I E
BLACK ROCK CANAL
SQUAW ISLAND
RIVER
NIAGARA
INTERNATIONAL RAILWAY BRIDGE
BLACK ROCK GAGE
LOCK
STATUTE MILES
0
½

FIGURE B-7

BLACK ROCK CANAL-BLACK ROCK LOCK

ALTERNATIVE L1



LOCATION MAP

FIGURE B-8

2.4.2 Short Period Water Level Fluctuations

Of the five Great Lakes, Lake Erie is the shallowest with an average depth from low water datum of 62 feet. The prevailing wind over the Lake Erie basin is south westerly which coincides with the longitudinal axis of the lake causing significant storm surge or wave setup. Of significance, also, is the oscillation of the lake surface produced by changes in wind and/or barometric pressure commonly referred to as a seiche. Wind-produced seiches follow cessation or shifts in wind direction after a period of relatively steady wind in one direction. A rise in water surface elevation, due to storm surge, of 5 feet above the prestorm level can be expected annually at Buffalo. The maximum recorded storm surge at the Buffalo gauge is about 8 feet. This elevation was utilized in the preliminary design of regulatory works.

2.4.3 Ice Problems

During winter, thin ice sheets may form in shallow areas of the Niagara River near shore. A heavy ice sheet may also form over extensive areas of the Black Rock Canal. However, the principal problem in the area is the breakup of the ice field in Lake Erie, which results in the passage of ice both down the river and into the canal. Ice floes have been observed with thicknesses up to 20 feet in the upper river and up to several feet in the canal. The Power Entities, PASNY and Ontario Hydro, employ icebreakers in the vicinity of their power intakes to maintain power diversions. Frazil and anchor ice conditions occur periodically, causing reductions in the cross-sectional area of the river channel and blocking power intakes thus reducing flows available for power generation. However, frazil and anchor ice problems are considered secondary to those caused by the breakup of the Lake Erie ice field.

Each winter, beginning in 1964 with the approval of the International Joint Commission, the Power Entities have installed a floating ice boom in Lake Erie, at the head of the Niagara River. The boom is normally placed in December and removed in April. The purpose of the ice boom is to reduce the frequency and duration of ice runs from Lake Erie. Placement of the boom hastens and lends stability to the formation of a natural ice arch that takes place near the head of the Niagara River nearly every winter. Once the ice arch is formed, the arch bears the normal pressure of lake ice. Under storm conditions, the boom is designed to submerge in the face of severe ice pressures thereby permitting some of the ice cover to pass. When the storm subsides and pressure is dissipated, the boom emerges to prevent continuing passage of ice. It has been generally successful in preventing severe ice jamming in the Niagara River.

Ice problems would have considerable impact on the hydraulic design and construction of any structure in the Niagara River and would affect, to a lesser degree, any diversion plan via the Black Rock Canal. Due to the complexity, variability, and indeterminate nature of the ice problem, detailed engineering evaluations were deferred. Although ice management features were incorporated into the preliminary designs and cost estimates

based on literature surveys and operational experience, the subject of ice problems should be thoroughly addressed in any advanced design of structures in the Niagara River.

2.4.4 Operational Constraints

Any diversion flow through the Black Rock Canal would have an adverse impact on both commercial and recreational navigation. To minimize this impact, diversions via the canal would be restricted to night hours during the navigation season. Operating plans were developed to be used in conjunction with the Squaw Island series "S" alternatives and another. somewhat more restrictive, plan to be used with the Black Rock Lock series "L" alternative. These operating plans are shown on Figures B-9 and B-10. Each of these operating plans would substantially limit the daily diversion flows on a seasonal basis in order to accommodate the overall navigation requirements in the Black Rock Canal. The effect of each operating plan on diversion flow in the canal is indicated by an efficiency factor. This factor represents the percentage of possible channel capacity available due to the imposed operating constraints.

2.4.5 Methodology

Steady-state mathematical models were developed for hydraulic analyses of the Upper Niagara River and the Black Rock Canal. Essentially, the models are computer programs which perform backwater computations under steady-state flow conditions. The Niagara River model extends from the Chippawa-Grass Island Pool to the head of the river at Buffalo, New York and utilizes a U. S. Army Corps of Engineers computer program entitled, "Steady-State Sub-Critical Flow Backwater Model for the Niagara River." A listing of this computer program is contained in Annex E. The Black Rock Canal model extends from the appropriate downstream confluence of the canal and river, depending upon the alternative under study, to the head of the canal at Buffalo Harbor. This model employs a computer program developed by the U. S. Army Corps of Engineers, Hydrologic Engineering Center, and entitled, "Computer Program 723-X6-L202A; HEC-2 Water Surface Profiles." The models were calibrated using flows and levels obtained by measurement programs conducted by Water Survey of Canada, Environment Canada, and Detroit District, U. S. Army Corps of Engineers.

The mathematical models were utilized to determine the nature and extent of channel enlargements and/or modifications needed to meet the hydraulic requirements of any selected regulation plan. For any given alternative, the models were used to determine the resulting water surface elevations and average channel velocities at strategic locations along the river and canal. In addition, channel capacities, channel excavation, length of control structures, and length and locations of associated bank and shore protection works were determined, based on output data from these models.

Cross sections of the river channel extending from the Slaters Point gauge, located at the head of the Chippawa-Grass Island Pool, to Lake Erie were incorporated into the Niagara River model. Backwater computations were then initiated at the Chippawa-Grass Island Pool, using the water level

OPERATING PLAN I FOR DIVERSION VIA BLACK ROCK CANAL
ALTERNATIVES S1, S2, and S3

ASSUMPTIONS:

1. Diversion flows in the Black Rock Canal will be limited to the following periods:

Mid-April to May - 12 hours per day
June to August - 8 hours per day
September to mid-December - 12 hours per day
Mid-December to mid-April - 24 hours per day

2. Commercial navigation in the Black Rock Canal will be permitted during the remaining periods.

3. Recreational navigation will be allowed unlimited use of the canal during the commercial navigation periods.

AVERAGE ANNUAL EFFICIENCY FACTOR*:

Average annual factor - 62.5 percent

SEASONAL VARIATION IN EFFICIENCY FACTOR*:

Mid-April to May - 50 percent
June to August - 33-1/3 percent
September to mid-December - 50 percent
Mid-December to mid-April - 100 percent

* Percentage of possible channel capacity available due to operating constraints.

Figure B-9

OPERATING PLAN II FOR DIVERSION VIA BLACK ROCK CANAL
ALTERNATIVE L1

ASSUMPTIONS:

1. Diversion flows in the Black Rock Canal will be limited to the following periods:

    Mid-April to May - 12 hours per day
    June to August - 8 hours per day
    September to mid-December - 12 hours per day
    Mid-December to mid-March - 24 hours per day

2. Diversion flows and navigation will not be permitted between mid-March and mid-April when the lock must be closed for annual maintenance.

3. Commercial navigation in the Black Rock Canal will be permitted during the remaining periods.

4. Recreational navigation will be allowed unlimited use of the canal during the commercial navigation periods.

AVERAGE ANNUAL EFFICIENCY FACTOR*:

    Average annual factor - 54.2 percent

SEASONAL VARIATION IN EFFICIENCY FACTOR*:

    Mid-March to mid-April - 0
    Mid-April to May - 50 percent
    June to August - 33-1/3 percent
    September to mid-December - 50 percent
    Mid-December to mid-March - 100 percent

* Percentage of possible channel capacity available due to operating constraints.

Figure B-10

determined from the Slaters Point stage-discharge rating curve, and continued upstream to the Buffalo gauge at Lake Erie. For the series "N" alternatives, it was necessary to determine the amount of dredging in the Niagara River needed to accommodate selected increases in outflow. The cross sectional areas corresponding to these enlargements were used in the backwater computations.

Cross sections of the Black Rock Canal and/or the Squaw Island diversion channel were incorporated into the Black Rock Canal mathematical model. Backwater computations for the series "L" alternatives were initiated at the confluence of the river and the downstream Black Rock Lock approach channel and continued upstream to the Buffalo gauge at Lake Erie. Likewise, backwater computations for the series "S" alternatives were initiated at the confluence of the river and the Squaw Island diversion channel site and continued upstream through the Black Rock Canal to the Buffalo gauge at Lake Erie.

Because plans of regulation were selected subsequent to study commencement, a range of hydraulic conditions which would likely encompass those of the selected plans were simulated and used for design purposes. Because the sizes and locations of control structures and the extent of channel enlargements are interrelated, optimization studies were carried out to determine the minimum cost of all regulatory works. The design and cost estimates for all regulatory works alternatives, under study, are presented in succeeding paragraphs.

2.5 *Design and Cost Estimates*

Common design criteria were used throughout the design process in order that a valid comparison of costs could be made between the various alternatives under study. All depths and heights given in this appendix are referred to Low Water Datum; all elevations are referred to the International Great Lakes Datum (IGLD). Low Water Datum of Lake Erie is 568.6 feet above mean water level at Father Point, Quebec, IGLD (1955) datum. The following paragraphs, unless otherwise noted, are generalized for all alternatives in light of the common design criteria utilized.

2.5.1 Topographic and Geotechnical Characteristics

The series "N" alternatives would be situated on the natural rock ledge which provides virtually full hydraulic control of the Niagara River discharge. The control structure for alternative N3 would be located approximately 300 feet downstream of the Peace Bridge at a section where the river's width is approximately 1,650 feet. Channel excavation would extend from 1,000 feet upstream from the Peace Bridge to a distance up to 2,400 feet downstream from the bridge. The area is bounded on the west by the Canadian shoreline and on the east by the United States shoreline (Bird Island Pier). Very little overburden is evident in this shallow reach of the river. Rock outcroppings are in evidence along the Bird Island Pier under low water conditions. The required control structure would be founded on bedrock. Channel excavation along the U. S. shoreline would require removal of primarily sound, durable bedrock.

The series "S" alternatives would be situated on either end of Squaw Island. Alternatives S1 and S2 would be located within the downstream third of the island in an area that has been used as a disposal site for many years. Large volumes of ash from a municipal incinerator and other debris have been deposited in this area and contained by a rubblemound dike constructed along the Niagara River side of the island. Both alternatives would require the construction of a diversion channel across Squaw Island. After stripping unsuitable material, select channel excavation material would be used to construct low earth dikes along the channel banks as required. Channel excavation up to 23 feet below LWD is assumed to be well within existing overburden. Alternative S3 would be located within the Bird Island Pier at the extreme upstream end of Squaw Island. A section of the existing pier would be removed to accommodate construction of the proposed control structure. No channel excavation is anticipated for alternative S3. The control structures for all series "S" alternatives would be founded on bedrock.

The series "L" alternatives would be located at the upstream end of the Black Rock Lock, adjacent to the existing guard gate. Sections of the existing guidewalls, on either side of the canal, would be removed to accommodate construction of the sector gates. The sector gate sill would be founded on bedrock at the same elevation as the adjacent lock structure. The required gate chambers would extend into the backfill on both sides.

The assumed top of rock in the vicinity of each alternative structure is based upon limited geotechnical information available from existing and/or previously studied projects in the immediate area. The bedrock underlying the overall study area is considered competent throughout as a medium on which structures can be built. The bedrock is generally characterized by one or more layers of dolomite, limestone, shale, gypsum anhydrite, and combinations thereof.

2.5.2 Hydraulic Design

Pursuant to the basic assumptions outlined in Section 2.4.1, uniform hydraulic conditions for Lake Erie were adopted in order to permit the hydrologic comparison of various regulation plans on a consistent basis. To present a range of hydraulic conditions that might result from limited regulation, for each alternative under consideration, Lake Erie outflows of 200,000 cfs, 248,000 cfs, and 265,000 cfs were supplemented with design flow increases of approximately 8,000 cfs, 20,000 cfs, and 30,000 cfs. For alternatives involving the Black Rock Canal, net increases in Lake Erie outflow would be somewhat less than design flow increases, due to the backwater effect in the main river channel. In addition, the maximum design capacity of series "L" and "S" alternatives would be limited by the existing dimensions of the Black Rock Lock chamber and/or the dimensions of the canal. The discharge capacity of each alternative was determined by backwater computations performed in accordance with the methodology discussed in Section 2.4.5. The effective discharge capacity of each study alternative is shown on Table B-1. The capacity shown for alternative N3 (six gates) was determined by rounding a straight line proportion between similar five and seven gate alternatives.

Table B-1 - Niagara River Area Regulatory Works
Discharge Capacities

Alternative	Increased Discharge (cfs) at Lake Erie Design Discharge of 200,000 cfs	248,000 cfs	265,000 cfs
S1-30	4,250 (6,800)	5,310 (8,500)	4,940 (7,900)
S1-75	9,560 (15,300)	11,810 (18,900)	11,940 (19,100)
S1-110	12,000 (19,200)	14,750 (23,000)	15,440 (24,700)
S2-30	4,250 (6,800)	5,250 (8,400)	5,000 (8,000)
S2-75	9,620 (15,400)	11,560 (18,500)	11,940 (19,100)
S2-110	12,000 (19,200)	14,620 (23,400)	15,310 (24,500)
S3-90 (1 gate)	3,870 (6,200)	5,000 (8,000)	5,000 (8,000)
S3-90 (2 gates)	7,120 (11,400)	8,250 (13,200)	8,870 (14,200)
S3-90 (3 gates)	9,560 (15,300)	11,620 (18,600)	12,060 (19,300)
L1-30' Open	3,680 (6,800)	4,390 (8,100)	4,340 (8,000)
L1-70' Open	8,670 (16,000)	10,460 (19,300)	10,840 (20,000)
N3-75 (3 gates)	8,600 (8,600)	11,000 (11,000)	10,500 (10,500)
N3-75 (5 gates)	20,700 (20,700)	25,000 (25,000)	26,300 (26,300)
N3-75 (6 gates)	25,000 (25,000)	30,000 (30,000)	31,500 (31,500)
N3-75 (7 gates)	28,600 (28,600)	34,500 (34,500)	36,500 (36,500)

4,250 - Numbers without brackets indicate net increased discharges after applying average annual efficiency factors based on Black Rock Canal proposed operating procedures.

(6,800) Numbers with brackets indicate maximum net increased discharges that would be possible without Black Rock Canal operating constraints.

2.5.3 Control Gates

The following general considerations were taken into account in selecting the type of control gate for each study alternative:

1. The gate must be capable of passing large amounts of ice and/or debris;

2. The normal operating head should range up to 5 feet;

3. At times, under storm surge conditions, a 15-foot increase in operating head could be accommodated;

4. Swift and efficient gate operation must be possible to satisfy emergency situations; and

5. The gate selected for the series "L" alternative must be capable of passing commercial vessels with drafts up to 21 feet.

Based upon these criteria, submersible tainter gates were selected for the series "N" and "S" alternatives and sector gates were chosen for the series "L" alternatives.

Due to the lower head conditions that would exist at the series "N" control works, multiple tainter gates would be required to accommodate the range of hydraulic conditions, under study. Each series "N" gate would be 75 feet wide and 40 feet high. For the same reason, alternative S3 would require up to three tainter gates, 90 feet wide by 23 feet high. A single tainter gate, 34 feet high and varying in width between 30 feet and 110 feet, would satisfy alternatives S1 and S2 conditions.

Although submersible tainter gates have proven effective in passing ice and debris, the use of other types of gates, such as radial submersible sector gates, was not ruled out. Submersible tainter gates were selected to determine representative gate costs for preliminary design purposes. The operational and economic feasibility of other types of gates would require investigation during detailed advanced engineering design and hydraulic model testing. This would be particularly important in view of the severe ice run conditions from Lake Erie.

Sector gates were selected for the series "L" alternatives to permit continued usage of the Black Rock Lock as a navigation facility. This type of gate has been used in navigation locks throughout the United States and Canada. The 70-foot wide by 33-foot high sector gates would satisfy operational and hydraulic requirements of limited regulation of Lake Erie.

2.5.4 Structural Design

Preliminary designs were prepared for control structures necessary to accommodate the two different types of gates selected in Section 2.5.3. The designs were based on structures proposed in previous regulation studies and/or a literature survey of existing practice. Although stability analyses

of the structures were not carried out, conservative dimensions were selected for each structural component. All control structures would be founded on bedrock. The following paragraphs describe the improvements that would be required.

The control structure for the series "N" alternatives would be a series of 15-foot wide reinforced concrete pier buttresses supporting the tainter gates and extending to the bottom of the gate sill. The number of 75-foot wide gate bays and overall structure width are dependent upon the requirements of the regulation plan under study. A minimum 20-foot deep sill block of concrete would be provided for the base of the structure to assure an adequate safety factor against overturning. In addition to the control structure, other appurtenant series "N" construction would include:

1. Raising and widening the existing Bird Island Pier between Squaw Island and the control structure to provide a roadway for truck access during construction and for future operation and maintenance;

2. A rock-filled work area in the river to connect the control structure with the improved Bird Island Pier;

3. A 25-foot by 25-foot masonry operations building located adjacent to the control structure; and

4. Temporary cellular steel sheet pile cofferdams in the river to facilitate subsequent construction of the control structure in-the-dry.

The control structures for the three series "S" alternatives would be similar to the series "N" structure. Due to less severe design criteria and smaller gate sizes, the width of each pier buttress and the minimum thickness of the sill blocks were reduced to 10 feet and 8 feet, respectively. The number of gate bays, gate width, and overall structure width are dependent on both the alternative and the regulation plan under study. Alternatives S1 and S2 would require either a 30-foot, 75-foot, or 110-foot tainter gate, whereas alternative S3 would utilize from one to three 90-foot gates to satisfy similar regulation plans. A footbridge would be constructed over the alternative S2 gate bay to permit maintenance access from the Black Rock Lock side. A similar enclosed footbridge would be provided over the alternative S3 gate bays to allow public access to the Bird Island Pier for recreational fishing. In addition to the control structure, other appurtenant series "S" construction would include:

1. A rock-filled work area in the river to connect the alternative S3 control structure with Squaw Island;

2. A 25-foot by 25-foot masonry operations building located adjacent to the alternative S3 control structure;

3. Temporary cellular steel sheet pile cofferdams to facilitate subsequent construction of the control structures in-the-dry;

4. A highway bridge across the alternative S1 diversion channel to permit public access to the northern portion of Squaw Island;

5. An open cellular steel sheet pile guardwall with connecting footbridges across the entrance to the proposed alternative S2 diversion channel;

6. A temporary ice boom across the Black Rock Canal at the upstream end of Bird Island Pier to restrict the passage of large ice floes into the canal during any series "S" diversion flow;

7. Fixed log booms across the upstream end of the alternatives S1 and S2 diversion channels to control floating debris and small-boat access to the control structure; and,

8. Installation of movable log booms across the Black Rock Canal upstream and downstream of the alternative S3 structure for the same purpose. The movable log booms would close the canal only during periods of diversion flow when the canal would be unsafe for navigation.

The control structure for the series "L" alternatives would be a pair of reinforced concrete gate chambers supporting the sector gates and extending to the top of the gate sill. The gate chambers would replace sections of the existing guidewalls. A 24-foot thick sill block of concrete would be provided for the base of the structure to assure an adequate safety factor against flotation. A stoplog system would enable dewatering of the gate bay and chambers for repairs and maintenance. Other appurtenant series "L" construction would include:

1. Temporary cellular steel sheet pile cofferdams around the landward sides of the proposed gate chambers to permit construction in-the-dry;

2. A reusable floating closure structure across the Black Rock Canal to permit quick dewaterings for two "time restricted" construction seasons; and,

3. Installation of a temporary ice boom and movable log boom across the Black Rock Canal similar to those proposed for alternative S3 above.

2.5.5 *Channel Enlargement*

As indicated in Section 2.4.5, the determination of the nature and extent of channel enlargement and/or modifications was carried out using mathematical models of the Niagara River and Black Rock Canal. Basically, there are three alternatives that require either channel enlargement or modifications, namely alternatives N3, S1, and S2. The following paragraphs summarize the necessary alterations.

Channel enlargement for alternative N3 would be required in the Niagara River above and below the Peace Bridge where a natural rock ledge controls the existing river discharge. The length and width of the areas requiring excavation are dependent on the regulation plan under study. Rock excavation, up to 17 feet in depth, would start approximately 1,000 feet upstream of the Peace Bridge for all plans and extend downstream from the bridge between 2,300 feet and 2,370 feet. The bottom width of the excavation would vary from 325 feet to 875 feet. Drilling and blasting would be

required to accomplish the excavation of approximately 400,000 cubic yards to 1,300,000 cubic yards of rock. This material is assumed to be environmentally clean and would be disposed of in a suitable open-lake disposal site.

Alternative S1 would require construction of a diversion channel skewed across Squaw Island immediately north of the existing International Railroad bridge. The alternative channel would bypass the Black Rock Lock and permit Lake Erie discharge via the Black Rock Canal. The length and width of the new channel would be dependent on the regulation plan under study. Earth excavation up to 29 feet in depth would start at the canal, approximately 350 feet downstream of the International Bridge, and extend across the island between 1,200 feet and 1,500 feet in length. The bottom width of the excavation would vary from 30 feet to 180 feet. Earth levees, upstream and downstream of the control structure, would provide protection against overtopping during extreme high levels. The quantity of earth excavation would range from approximately 100,000 cubic yards to 300,000 cubic yards. Part of the material would be used for levee construction and the remainder would be disposed of in the adjacent City of Buffalo disposal area. Removal of up to 800 feet of an existing steel sheet pile wall along the Black Rock Canal and up to 450 feet of an existing stone dike along the Niagara River would be required to complete the diversion channel.

Alternative S2 would require construction of a diversion channel across Squaw Island parallel with and immediately adjacent to the existing Black Rock Lock. This channel would function similarly to the alternative S1 channel. The length and width of this channel would be dependent on the regulation plan under study. Earth excavation, up to 25 feet in depth, would begin at the Black Rock Canal, approximately 900 feet downstream of the International Railroad bridge, and extend 1,600 feet along the east side of the island. The bottom width of the excavation would vary from 50 feet to 250 feet. Earth and rock levees, upstream and downstream of the control structure, would provide adequate freeboard along the east side of the island. The quantity of channel excavation would range from approximately 100,000 cubic yards to 350,000 cubic yards. Part of the material would be used for earth levee construction, and the remainder would be disposed of in the adjacent City of Buffalo disposal area. Removal of up to 80 feet of an existing steel sheet pile wall and 320 feet of an existing concrete-capped timber crib guide wall, both along the Black Rock Canal, and up to 380 feet of an existing stone dike along the Niagara River would be required to complete the diversion channel.

2.5.6 Bank Protection

Bank protection along critical velocity reaches of the existing Black Rock Canal and the Squaw Island diversion channel would be required with any series "S" or "L" alternative that provides a mid- to high-range increase in Lake Erie outflow. The determination of the extent of bank protection was based on an onsite evaluation of the canal banks and velocity profiles of both the canal and diversion channel as generated by the mathematical model of the Black Rock Canal discussed in Section 2.4.5.

Based on the type and/or condition of existing structures and natural sideslopes, Alternatives S1 and S2 would require bank protection along the existing canal from 2,500 feet upstream of the Peace Bridge to the Black Rock Lock and along the proposed diversion channels. The locations and amount of required bank protection are dependent on the regulation plan under study. Between 500 feet and 4,850 feet of 18-inch riprap protection would be provided along the earthen canal banks with either alternative. Up to 1,920 feet and 1,050 feet of additional 24-inch riprap protection would be provided along the diversion channel sideslopes for Alternatives S1 and S2, respectively. Between 1,050 feet and 6,850 feet of steel sheet pile bulkheads would be constructed around bridge abutments and along the right (east) bank of the canal adjacent to the thruway under Alternative S1. Likewise, between 400 feet and 6,850 feet of steel bulkheads would be constructed for Alternative S2. Under Alternative S2, up to 1,250 feet of 36-inch riprap toe protection would be placed on the canal bottom along the steel sheet pile and timber pile bulkheads downstream of the International Railroad bridge.

Alternative S3 would require bank protection along the existing canal from 2,500 feet upstream of the Peace Bridge to Squaw Island. The locations and quantity of protection are once again dependent on the regulation plan under study. Up to 1,000 feet of 18-inch riprap protection would be provided along the earthen right bank of the canal upstream of the Peace Bridge. Between 300 feet and 800 feet of heavy armor stone would be placed on the left (west) bank of the canal, around the control structure, and along the Bird Island Pier downstream of the Peace Bridge. Between 400 feet and 3,000 feet of steel sheet pile bulkheads would be constructed along the right bank of the canal upstream and downstream of the Peace Bridge.

Alternative L1 would require bank protection along the existing canal from 2,500 feet upstream of the Peace Bridge to the Black Rock Lock. The locations and extent of protection vary with the regulation plan under study. Between 500 feet and 2,650 feet of 18-inch riprap protection would be provided along the earthen canal banks upstream and downstream of the Peace Bridge. Up to 1,100 feet of 36-inch riprap toe protection would be placed on the canal bottom along the bulkheads and lock guidewalls downstream of the International Railroad bridge. Up to 1,050 feet of steel sheet pile bulkheads would be constructed around the abutments of the International bridge and along the Ferry Street bridge right abutment.

2.5.7 Shore Protection Works

The extra discharge capacity provided by the series "L," "S," and "N" alternatives would not be used if water supply conditions to Lake Erie were at or below normal. However, in the case of the series "N" alternative, closure of the gates would produce river levels higher than preproject from the control structure to a point somewhat downstream from the lake's outlet. Therefore, during storm surge conditions at the eastern end of Lake Erie the accompanying temporary water level rises would be a matter of concern. A lake outflow of 295,000 cfs with gates closed would raise the water level about 3 feet immediately upstream from the control structure. To mitigate the adverse impact of this rise on the Canadian shoreline, the existing stone

masonry wall which extends from about 7,700 feet upstream to about 800 feet downstream from the Peace Bridge would have to be raised from 1 to 3 feet and backfilled with an earth berm. No additional protection would be needed on the United States shoreline.

In the event of storm surges which produce Niagara River flows substantially in excess of 295,000 cfs, flooding has occurred and will continue to occur in specific areas upstream from Niagara Falls in both countries. In such instances, regardless of supply conditions to Lake Erie, the control structure gates would be closed only enough to compensate for the additional outflow made possible by the project dredging.

2.5.8 Cost Estimates

: Cost estimates for the study alternatives were based on unit costs used on similar U.S. Army Corps of Engineers projects and expressed in July 1979 price levels. Corresponding costs for each project feature were developed for the discharge capacities required to fulfill the various regulation plans under study. Major features include the following:

1. Control structures either in the Niagara River, on Squaw Island, or on Bird Island pier;

2. Black Rock Lock modifications;

3. Niagara River deepening;

4. Squaw Island diversion channels;

5. Black Rock Canal bank protection; and,

6. Shore protection along the Canadian shoreline of the upper Niagara River.

These costs were added together and escalated by a 25 percent contingency allowance to obtain the total direct costs. Indirect costs, which include allowances for detailed investigations, foundation explorations, engineering designs, and construction supervision and administration, were estimated at 15 percent of the total direct costs and added to obtain the total estimated construction costs. An engineering appraisal of real estate costs, including lands and damages, was prepared and added to the total construction costs, where applicable, to obtain the total estimated first costs shown on Table B-2. Land costs were based on the assessed value of the required lands as recorded by the City of Buffalo and adjusted by the current New York State equalization factor of 42.69 percent to obtain the fair market value. Alternatives S1 and S2 would require acquisition of up to 14 acres of an existing City of Buffalo disposal area located at the northern end of Squaw Island. Damages due to the project were assessed to compensate the City of Buffalo for the additional costs that would be incurred to dispose of a volume of material equal to the disposal area volume lost during the remaining 10-year life of the affected area.

Table B-2 - Niagara River Area Regulatory Works
Discharge Capacities and Cost Estimates

Alternative	Increased Discharge Capacities 1/2/ in Cubic Feet Per Second	Cost Estimates 3/ in Millions of Dollars		
		First Costs	Average Annual Costs	Present Worth
S1-30	4,250 (6,800)	$ 11.62	$ 1.22	$ 14.05
S1-75	9,560 (15,300)	18.57	1.90	21.93
S1-110	12,000 (19,200)	28.38	2.86	33.02
S2-30	4,250 (6,800)	11.16	1.17	13.47
S2-75	9,620 (15,400)	19.63	1.95	22.52
S2-110	12,000 (19,200)	32.02	3.17	36.67
S3-90 (1 gate)	3,870 (6,200)	10.24	1.16	13.36
S3-90 (2 gates)	7,120 (11,400)	17.17	1.87	21.58
S3-90 (3 gates)	9,560 (15,300)	26.08	2.78	32.14
L1-30' Open	3,680 (6,800)	10.31	1.19	13.80
L1-70' Open	8,670 (16,000)	13.12	1.49	17.24
N3-75 (3 gates)	8,600 (8,600)	56.51	5.97	69.01
N3-75 (5 gates)	20,700 (20,700)	93.83	9.81	113.38
N3-75 (6 gates)	25,000 (25,000)	111.39	11.61	134.25
N3-75 (7 gates)	28,600 (28,600)	129.55	13.49	155.90

Notes:

1/ Discharge capacities are shown for a Lake Erie design discharge of 200,000 cubic feet per second. Corresponding capacities for design discharges of 248,000 and 265,000 cubic feet per second are shown on Table B-1.

2/ 4,250 - Numbers without brackets indicate net increased discharges after applying average annual efficiency factors based on Black Rock Canal proposed operating procedures.
(6,800) - Numbers with brackets indicate maximum net increased discharges that would be possible without Black Rock Canal operating constraints.

3/ Cost estimates are based on July 1979 price levels, a 50-year economic project life and an 8-1/2 percent interest rate. They include construction costs, land costs, and damages.

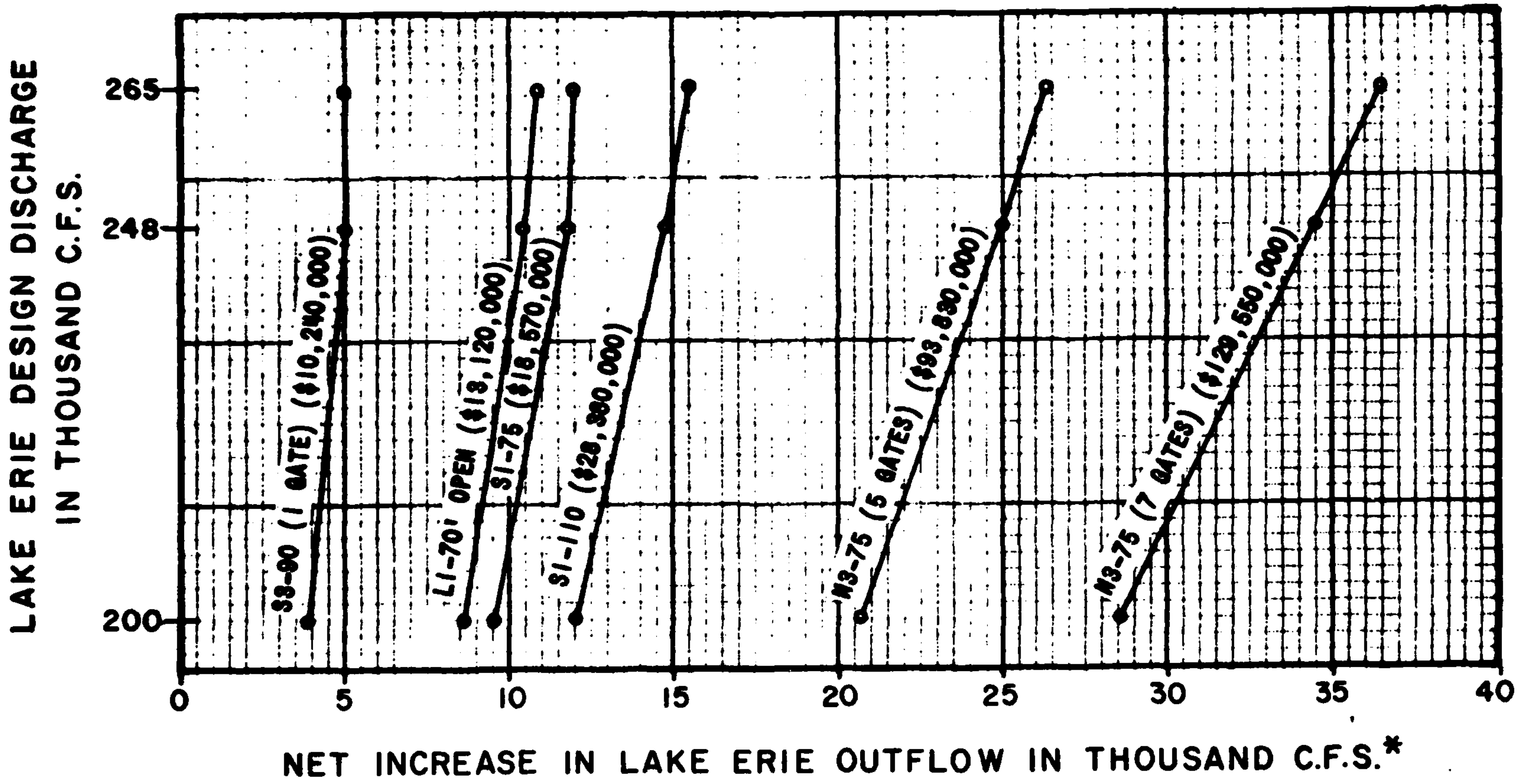
First Cost Optimization: Reviewing the discharge capacities and cost estimates shown on Tables B-1 and B-2, respectively, indicates the following conclusions. Alternative N3 is the only alternative offering a net increase in Lake Erie outflow in excess of 16,000 cfs at a cost ranging between $93 and $130 million. Alternatives S1 and S2 are very close in discharge capacities and total costs, ranging between $11 and $32 million. Alternative S3, ranging between $10 and $26, appears favorable for net increases below 5,000 cfs. Alternative L1 appears favorable for net increases up to 9,000 cfs maximum with total costs ranging between $10 and $13 million. A composite discharge capacity curve, Figure B-11, shows an array of optimum alternatives and their possible net increases in Lake Erie outflow for the range of Lake Erie design discharges under consideration. A composite cost curve, Figure B-12, shows the optimum first costs for three Lake Erie design discharges and a range of net increases in Lake Erie outflow.

Annual Costs: Annual costs, comprised of financial costs and operation and maintenance costs, are summarized in Table B-3 for each of the study alternatives. The total average annual costs are also tabulated in Table B-2 along with increased discharge capacities for ready comparison. The following paragraphs discuss these annual costs in further detail.

Annual financial costs were estimated based on an interest rate of 8-1/2 percent, an economic project life assumed as 50 years, and a construction period assumed as three years for Alternatives S1, S2, and S3, and four years for Alternatives L1 and N3. Interest during construction was computed at a rate of 8-1/2 percent for half the construction period and added to the project first costs to determine the total investment cost. Damages associated with real estate acquisition for Alternatives S1 and S2 were distributed in 10 equal payments over the assumed 10-year life of the affected Squaw Island disposal area. The resultant annual damages were converted to net present worth and substituted for the total damages previously included in the first costs shown in Table B-2. Financial cost calculations for Alternatives S1 and S2 were based on these revised and reduced first costs. Interest charges computed at 8-1/2 percent were added to the amortization costs for the assumed 50-year economic project life to determine the total annual financial costs, summarized in Table B-3.

Annual operation costs were estimated based on a four-man operating staff. Annual maintenance costs were estimated based on a percentage of first costs excluding real estate costs (lands and damages) and rock excavation (Alternative N3 only). This assumes that the deepened channel in the Niagara River, required for Alternative N3, will be self-maintaining due to anticipated high velocities. Provision of a 0.3 percent factor is considered adequate for the conditions and magnitude of Alternative N3. Provision of a 0.5 percent factor for Alternatives S1, S2, S3, and L1 was based on indeterminate conditions along the Black Rock Canal and the significantly lower magnitude cost of these alternatives. The reduced first costs were multiplied by the applicable maintenance percentage factor to determine the total annual maintenance costs, summarized in Table B-3.

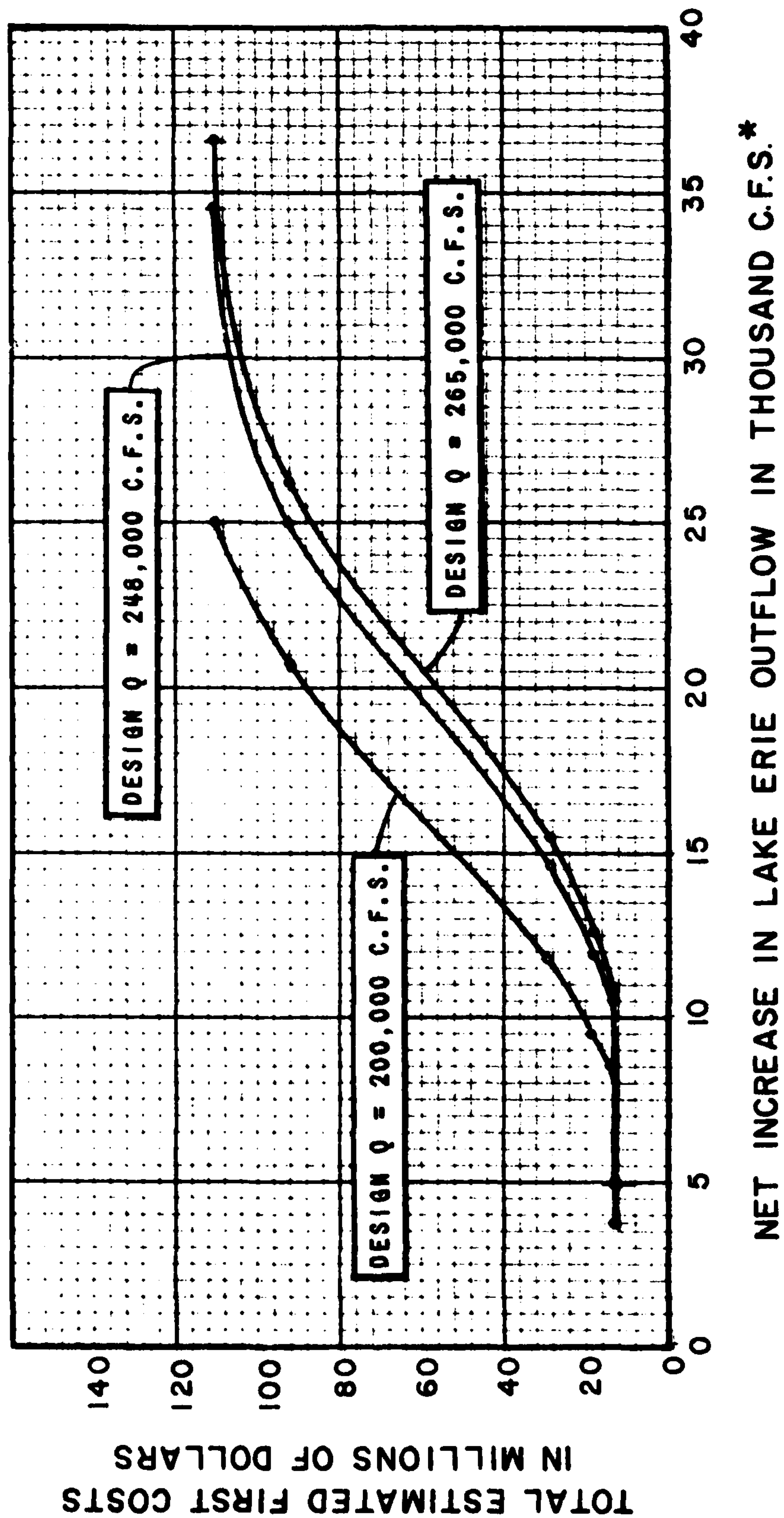
NIAGARA RIVER AREA REGULATORY WORKS
DISCHARGE CAPACITY VERSUS LAKE ERIE DESIGN DISCHARGE



*AFTER APPLYING AVERAGE ANNUAL EFFICIENCY FACTORS BASED ON BLACK ROCK CANAL OPERATING PROCEDURES (FIG. 9 & 10)

FIGURE B-11

NIAGARA RIVER AREA REGULATORY WORKS
DISCHARGE CAPACITY VERSUS FIRST COSTS



* AFTER APPLYING AVERAGE ANNUAL EFFICIENCY FACTORS BASED ON BLACK ROCK CANAL OPERATING PROCEDURES (FIG. 9 & 10)

FIGURE B-12

Table B-3 - Niagara River Area Regulatory Works
Summary of Annual Costs

Alternative	Annual Costs (Millions of Dollars)			
	Financial	Operation	Maintenance	Total
	$	$	$	$
S1-30	1.06	0.11	0.05	1.22
S1-75	1.71	0.11	0.08	1.90
S1-110	2.63	0.11	0.12	2.86
S2-30	1.01	0.11	0.05	1.17
S2-75	1.76	0.11	0.08	1.95
S2-110	2.93	0.11	0.13	3.17
S3-90 (1 gate)	1.00	0.11	0.05	1.16
S3-90 (2 gates)	1.67	0.11	0.09	1.87
S3-90 (3 gates)	2.54	0.11	0.13	2.78
L1-30 Feet Open	1.04	0.10	0.05	1.19
L1-70 Feet Open	1.33	0.10	0.06	1.49
N3-75 (3 gates)	5.72	0.14	0.11	5.97
N3-75 (5 gates)	9.50	0.14	0.17	9.81
N3-75 (6 gates)	11.27	0.14	0.20	11.61
N3-75 (7 gates)	13.12	0.14	0.23	13.49

Present Worth: Estimates of present worth for each of the study alternatives are tabulated in Table B-2. Present worth was calculated based on a 50-year economic project life and the investment costs discussed above under annual financial costs. The net present worth of the annual operation and maintenance costs was added to the investment cost to determine the total present worth of each alternative.

2.6 Regulatory Works Alternatives

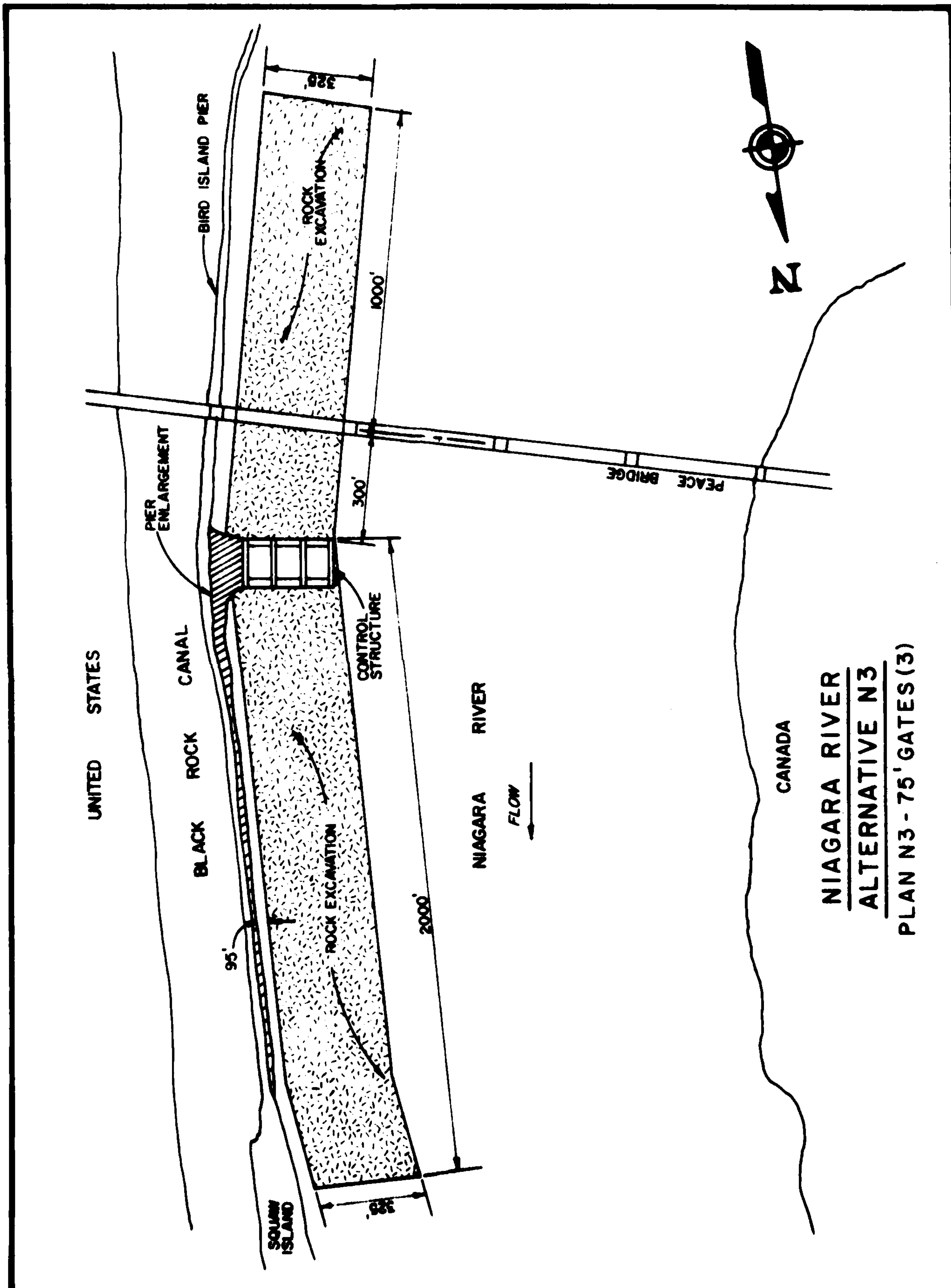
As stated in Section 2.3, preliminary studies were undertaken for five out of seven possible structural alternatives. The following is a summary of the regulatory works and remedial measures that would be required to implement each of these five alternatives. Discharge capacities of each alternative are listed for the critical Lake Erie design discharge of 200,000 cubic feet per second.

2.6.1 Alternative N3

Alternative N3 would require construction of a multi-gated control structure in the Niagara River and dredging within the river in the vicinity of the Peace Bridge. In addition, shore protection along the Canadian shoreline would be required at critical locations upstream of the control structure to mitigate adverse impacts due to increased water surface elevations which could occur in this area during storm surges (see Section 2.5.7). Four variations of structure size and dredging limits were studied to develop a discharge capacity versus first cost curve to accommodate a range of regulation plans.

The control structure would be located adjacent to the Bird Island pier and approximately 300 feet downstream from the existing Peace Bridge. The structure would extend between 400 feet and 750 feet into the river and would contain three to seven remote-controlled submersible tainter gates, 75 feet wide by 40 feet high. The entire structure would be equipped for year-round operation. Construction of the structure would require extensive cofferdams and would be hampered by the lack of adequate land access. The Peace Bridge area of the river provides substantial natural regulation due to its existing restricted dimensions. Extensive compensatory dredging, adjacent to the Bird Island pier, would extend from 1,000 feet upstream of the Peace Bridge to between 2,300 feet and 2,370 feet downstream and would vary in width from 325 feet to 875 feet. Dredging would involve principally rock excavation, up to 17 feet in depth. The existing shore protection along the Canadian shoreline would be raised from 1 to 3 feet for a distance of 8,000 feet upstream from the proposed control structure. Descriptive plans of the four alternative N3 variations and a longitudinal section through the control structure are shown on Figures B-13 through B-17, respectively.

Although location of the N3 control structure on the Fort Erie side of the river could satisfy hydraulic requirements of limited regulation of Lake Erie, the structure was located on the U.S. shore adjacent to the Bird Island



NIAGARA RIVER
ALTERNATIVE N3
PLAN N3 - 75' GATES(3)

FIGURE B-13

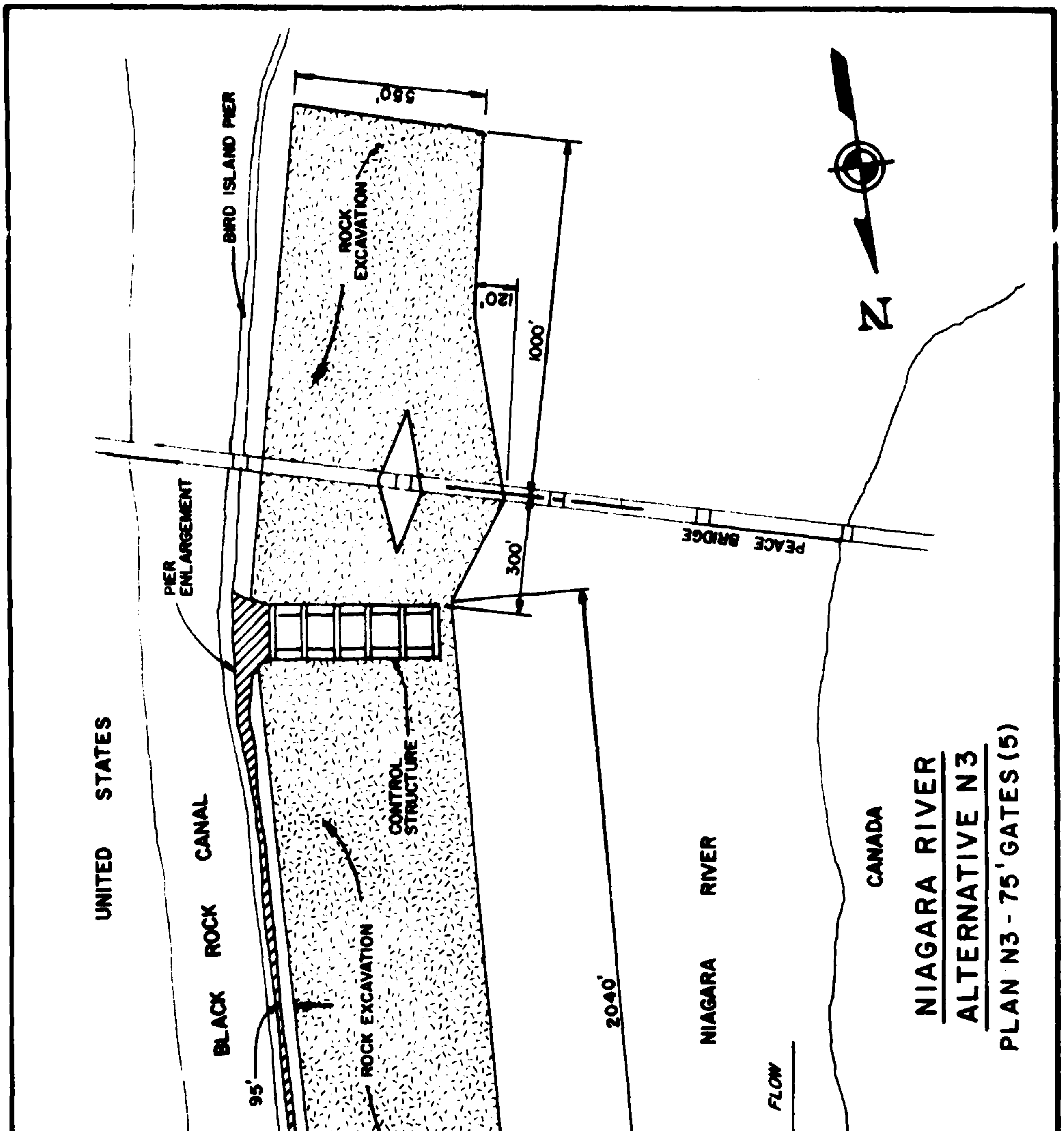
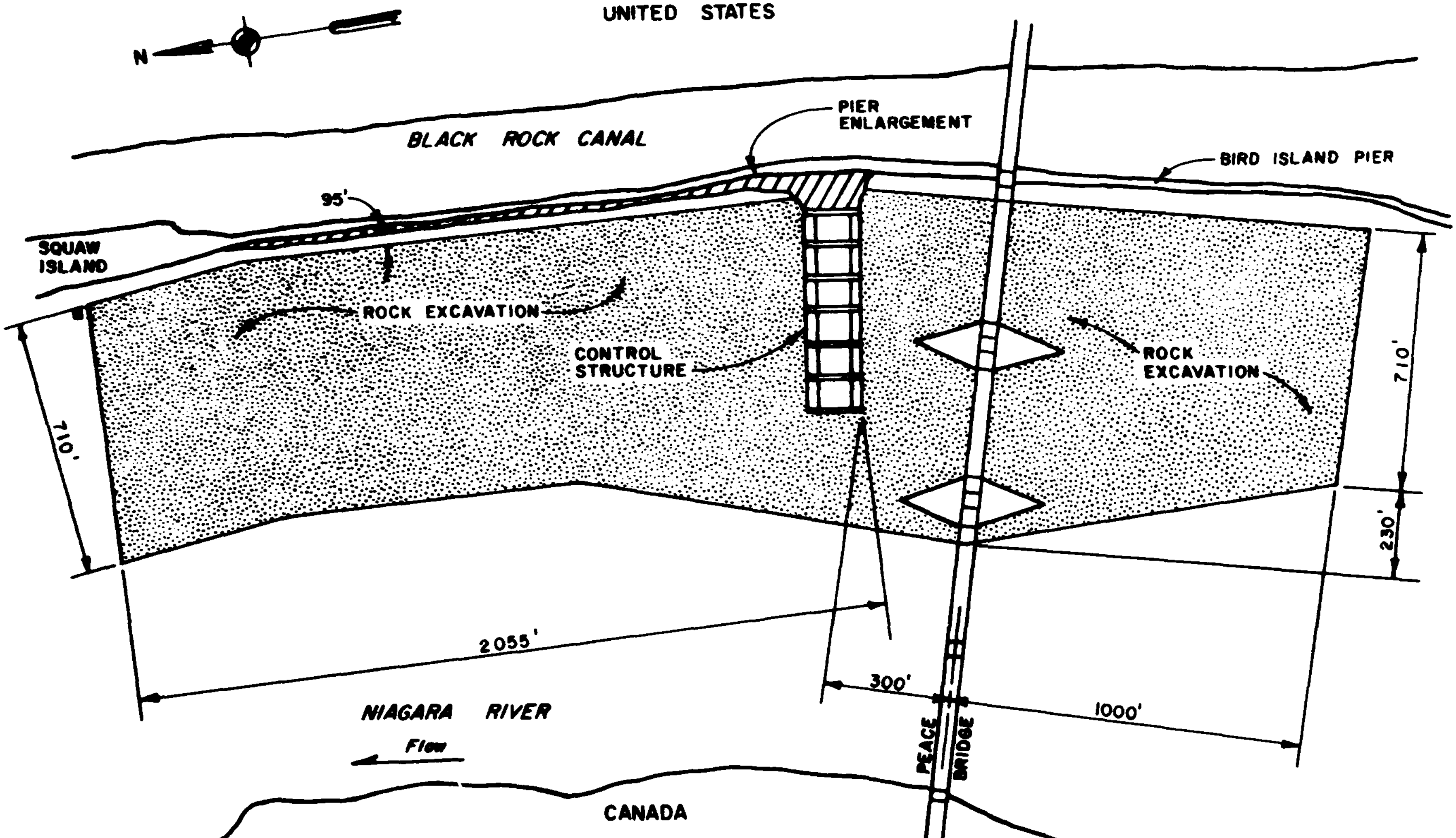

N
BIRD ISLAND PIER
ROCK EXCAVATION
580'
120'
1000'
300'
PEACE BRIDGE
PIER ENLARGEMENT
CONTROL STRUCTURE
UNITED STATES
BLACK ROCK CANAL
NIAGARA RIVER
CANADA
FLOW
95'
ROCK EXCAVATION
2040'
580'
SQUAW ISLAND
NIAGARA RIVER
ALTERNATIVE N3
PLAN N3 - 75' GATES (5)

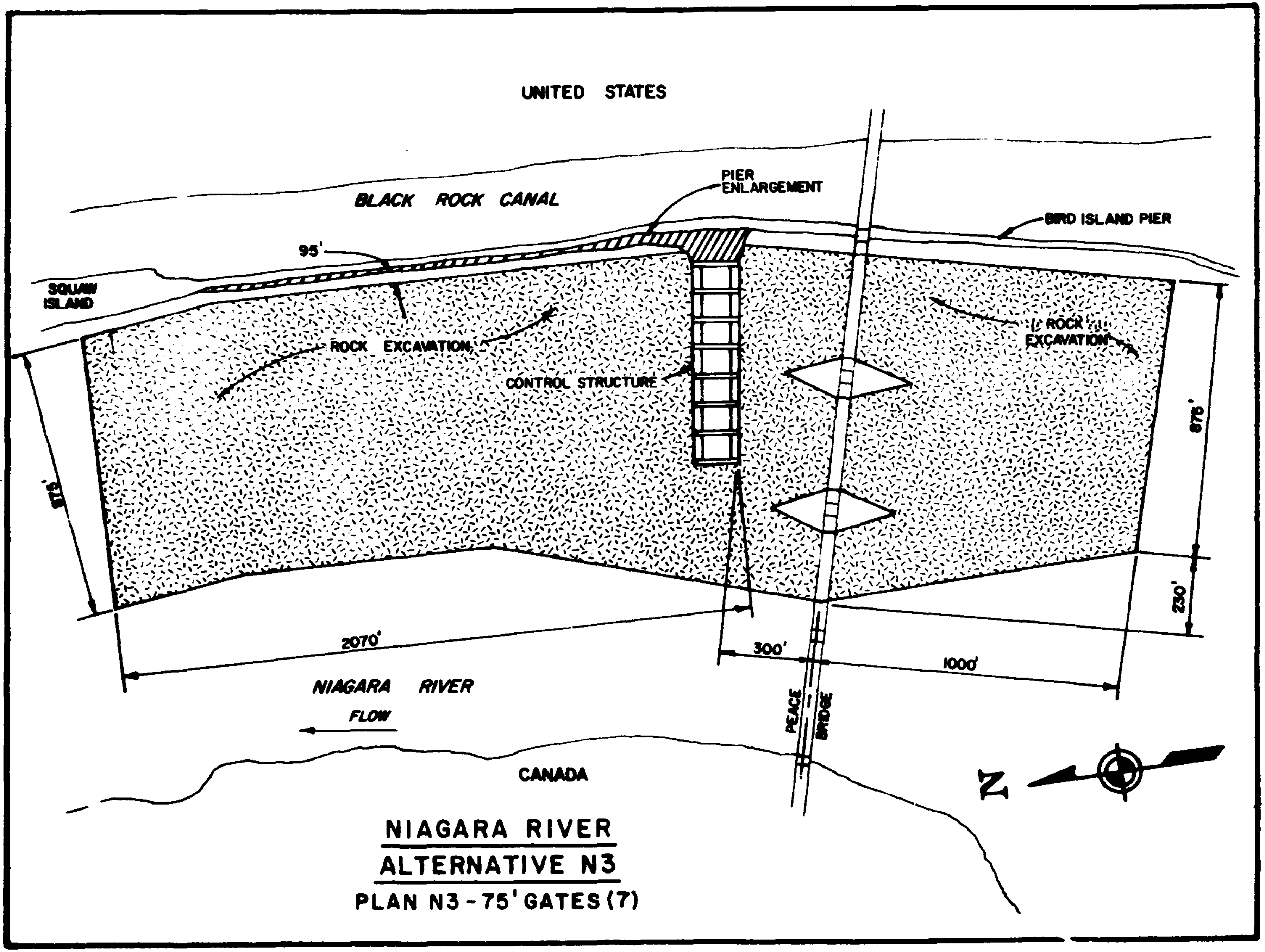
FIGURE B-14



NIAGARA RIVER

ALTERNATIVE N3

PLAN N3 - 75' GATES (6)

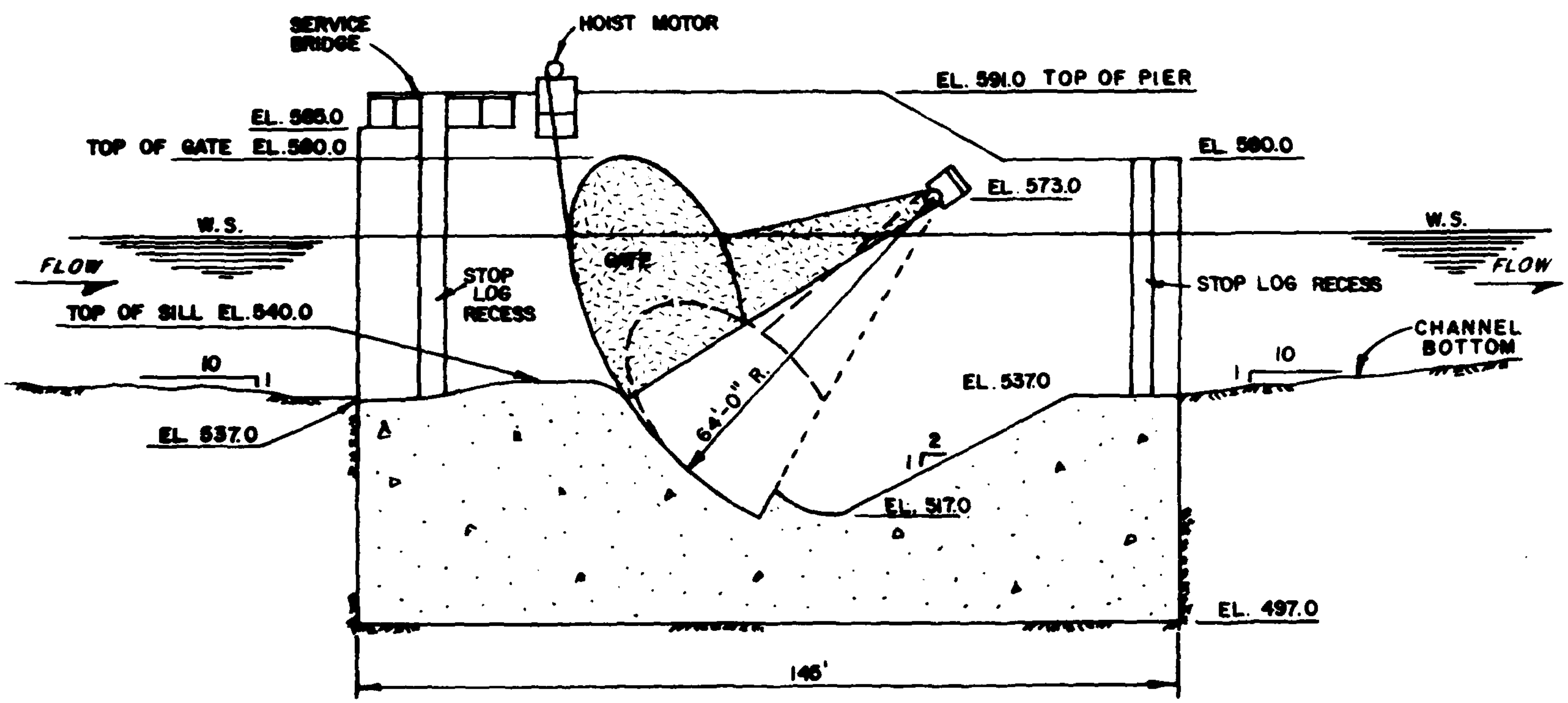


NIAGARA RIVER

ALTERNATIVE N3

PLAN N3 - 75' GATES (7)

FIGURE B-16



NIAGARA RIVER

ALTERNATIVE N3

CENTERLINE PROFILE OF CONTROL STRUCTURE

FIGURE B-17

Pier in a somewhat arbitrary manner. However, the following rationale had a bearing on this location:

1. A control structure on the Fort Erie side of the river is considered to be environmentally less desirable due to the resultant disturbance of the fishery along the Canadian shore and the Niagara Parks Commission lands; and

2. Physical operation and maintenance of the control structure on the United States shore would be assisted by its close proximity to existing Corps of Engineers facilities at the Black Rock Lock and the sharing of personnel and equipment.

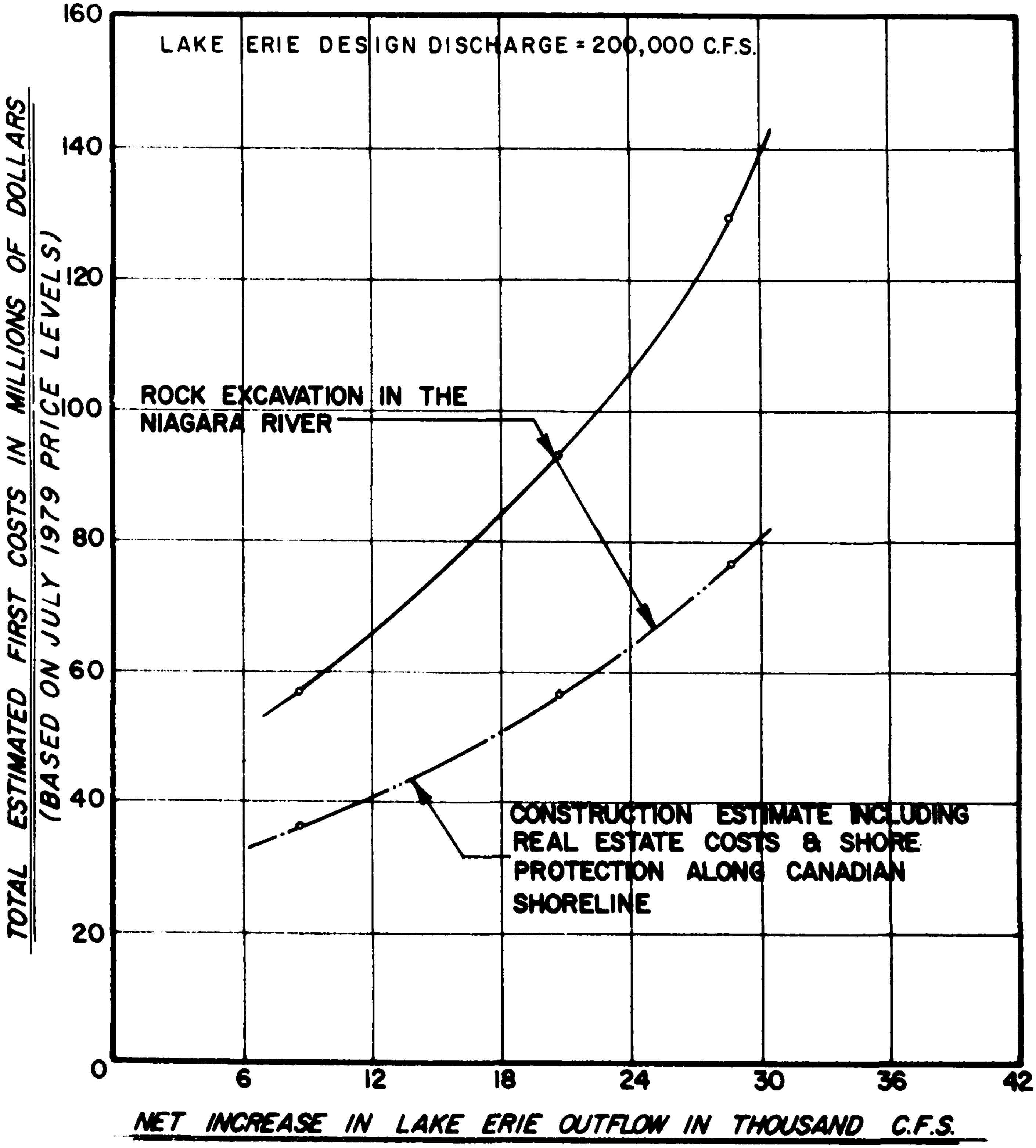
The increased discharge capacity of Alternative N3 varies from 8,600 cubic feet per second for a three gate structure to 28,600 cubic feet per second for a seven gate structure. The first costs of the studied control structure, compensatory dredging, and appurtenant works would range from approximately \$56.5 to \$129.6 million. A discharge capacity versus first cost curve for Alternative N3 is shown on Figure B-18 for a Lake Erie design discharge of 200,000 cubic feet per second. Corresponding annual costs, after adjustments for finance, operation, and maintenance costs, are estimated to range from \$6.0 to \$13.5 million. Figure B-19 shows a first cost versus annual cost curve for Alternative N3. Discharge capacities and a cost summary, including first costs, annual costs, and present worth, are shown on Table B-2.

2.6.2 Alternative S1

Alternative S1 would require construction of a control structure and diversion channel across the downstream end of Squaw Island along a previously selected alignment. In addition, bank protection would be required at critical locations along the Black Rock Canal and the diversion channel, as necessary. Three different sizes of control structures and diversion channels were studied to develop a discharge capacity versus first cost curve for a range of regulation plans.

The control structure would be located within the diversion channel and about 1,000 feet from the Black Rock Canal. The structure would contain a remote-controlled submersible tainter gate, 34 feet high by either 30 feet, 75 feet, or 110 feet wide. The entire structure would be equipped for year-round operation. A diversion channel varying in width from 30 feet to 180 feet would extend across Squaw Island between 1,200 feet and 1,500 feet. The length and width of the channel along with the control gate size would vary to accommodate different regulation plans. Channel excavation, principally earth, would extend up to 29 feet in depth. The 1 on 2.5 side-slopes, upstream and downstream of the control structure, would be protected with riprap bank protection at critical locations to prevent erosion. Earth levees, with a top width of 10 feet and 1 on 2.5 sideslopes, would be constructed on either side of the diversion channel to provide adequate freeboard. Bank protection along the Black Rock Canal would be provided around bridge abutments and other high velocity restricted reaches dependent upon the stability of the existing sideslopes and/or structures. A traffic control system would be provided at the upstream entrance to the canal to

NIAGARA RIVER
ALTERNATIVE N3
DISCHARGE CAPACITY VERSUS FIRST COSTS



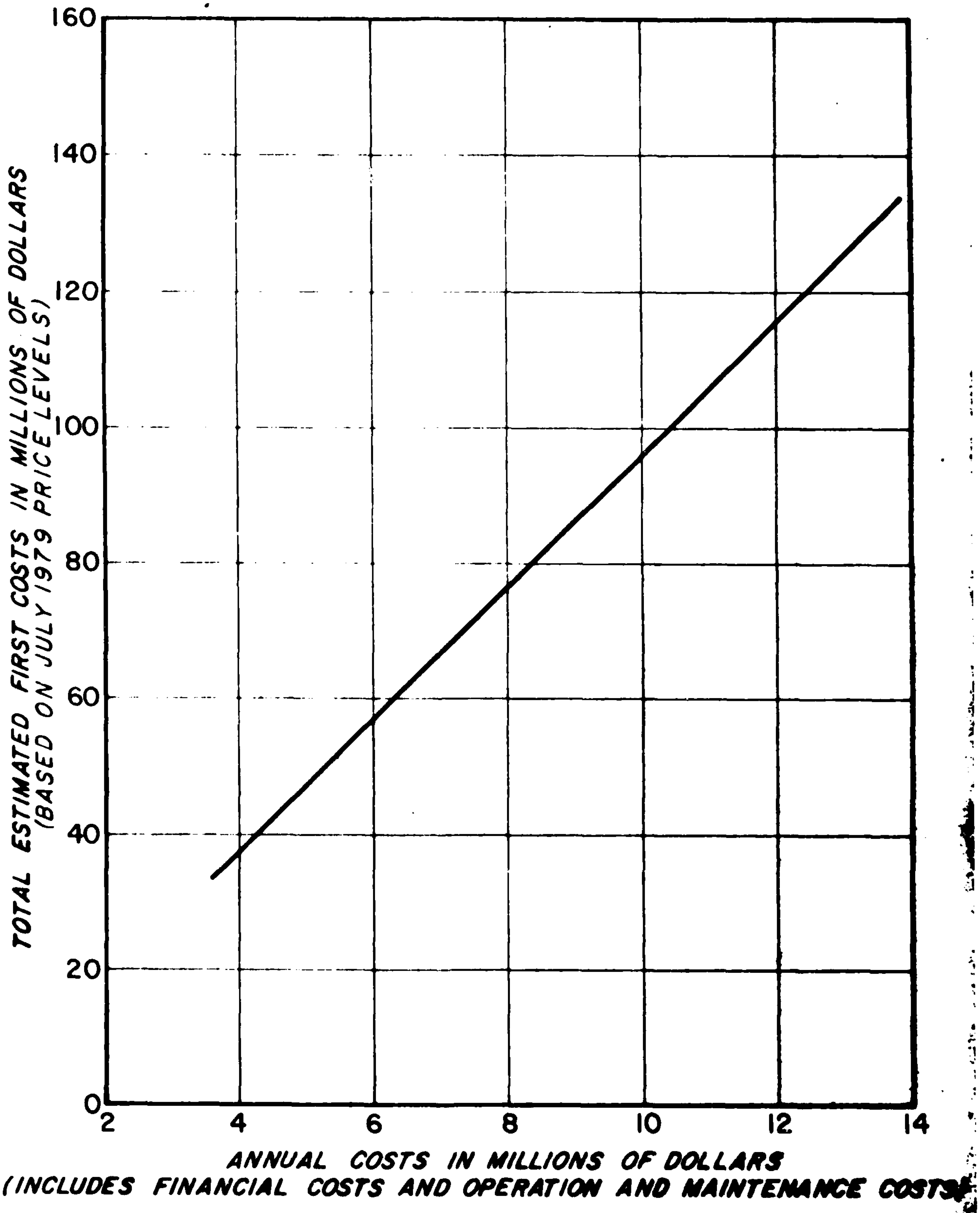
* WITHOUT OPERATING CONSTRAINTS

FIGURE B-18

NIAGARA RIVER

ALTERNATIVE N3

ANNUAL COSTS VERSUS FIRST COSTS



*WITHOUT OPERATING CONSTRAINTS

FIGURE B-19

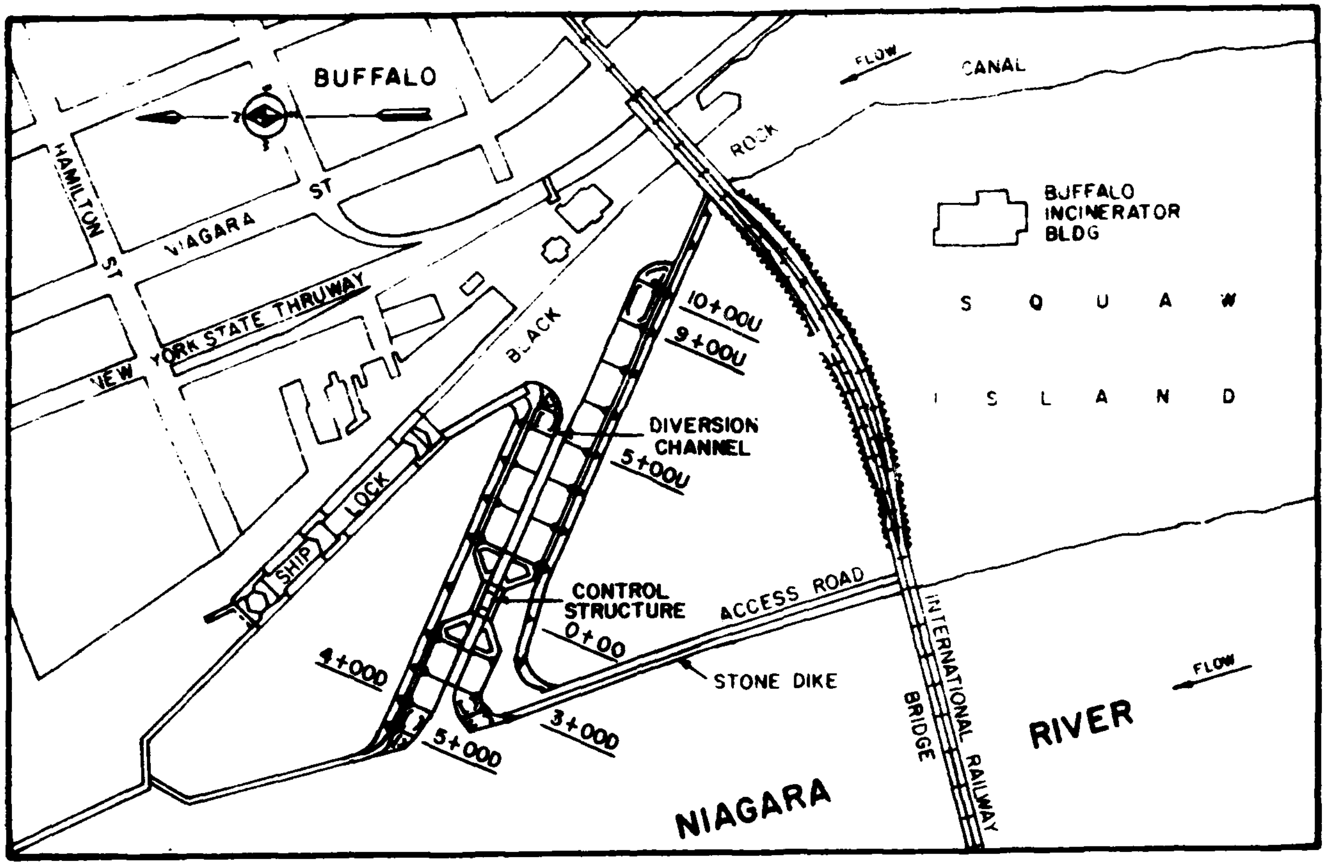
warn vessels that the canal may become dangerous during the operation of the control structure. A highway bridge would be constructed across the diversion channel to maintain public access to the downstream end of the island. Descriptive plans of the three Alternative S1 variations, a longitudinal section through the control structure and cross sections of the diversion channel, are shown on Figures B-20 through B-24, respectively.

The maximum increased discharge capacity of Alternative S1 without Black Rock Canal operating constraints varies from 6,800 cubic feet per second for a 30-foot gate structure to 19,200 cubic feet per second for a 110-foot gate structure. Utilization of the canal for diversion flows would require capacity reductions based on the operating plan shown on Figure B-9. The corresponding reduced capacities for Alternative S1 would vary from 4,250 to 12,000 cubic feet per second. The first costs of the control structure, diversion channel, and appurtenant works would range from approximately $11.6 to $28.4 million. A discharge capacity versus first cost curve for Alternative S1 is shown on Figure B-25 for a Lake Erie design discharge of 200,000 cubic feet per second. Corresponding annual costs, after adjustments for finance, operation, and maintenance costs, are estimated to range from $1.2 to $2.9 million. Figure B-26 shows a first cost versus annual cost curve for Alternative S1. Discharge capacities and a cost summary, including first costs, annual costs, and present worth, are shown on Table B-2.

2.6.3 Alternative S2

Alternative S2 would require construction of a control structure and diversion channel across the downstream end of Squaw Island along an alignment parallel and adjacent to the existing Black Rock Lock. In addition, bank protection would be required at critical locations along the Black Rock Canal, as necessary. A discharge capacity versus first cost curve was developed for a range of regulation plans based on three variations of control structure and diversion channel size.

The control structure would be located within the diversion channel and adjacent to the downstream lock miter gates. The structure would contain a remote-controlled submersible tainter gate, 34 feet high by either 30 feet, 75 feet, or 110 feet wide. The entire structure would be equipped for year-round operation. A diversion channel varying in width from 50 feet to 250 feet would extend along the existing lock approximately 1,600 feet. The length and width of the channel along with the control gate size would vary to accommodate different regulation plans. Channel excavation, principally earth, would extend up to 25 feet in depth. The 1 on 2.5 sideslope, upstream of the control structure, would be protected with riprap bank protection to prevent erosion. An earth levee, with a top width of 10 feet and 1 on 2.5 sideslopes, would be constructed along the east side of the island upstream of the control structure to provide adequate freeboard. Downstream of the structures a rock levee would be constructed with a top width of 10 feet, a 1 on 1.5 landward sideslope, and a 1 on 2 channel sideslope. Bank protection along the Black Rock Canal and a traffic control system would be provided similar to the Alternative S1 facilities. Descriptive plans of the three Alternative S2 variations, a longitudinal section through the control structure and cross sections of the diversion channel, are shown on Figures B-27 through B-31, respectively.



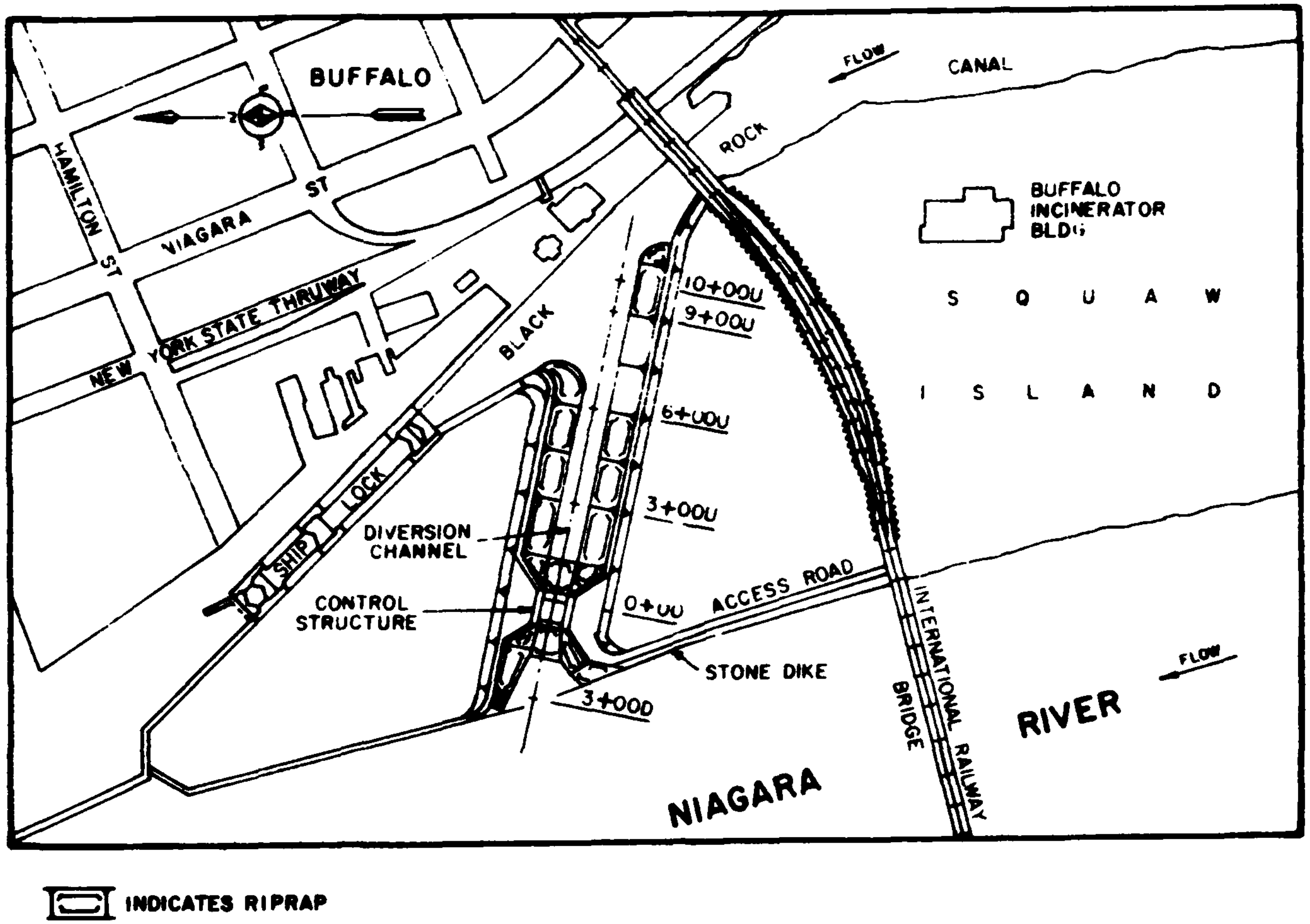
INDICATES RIPRAP

BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE SI

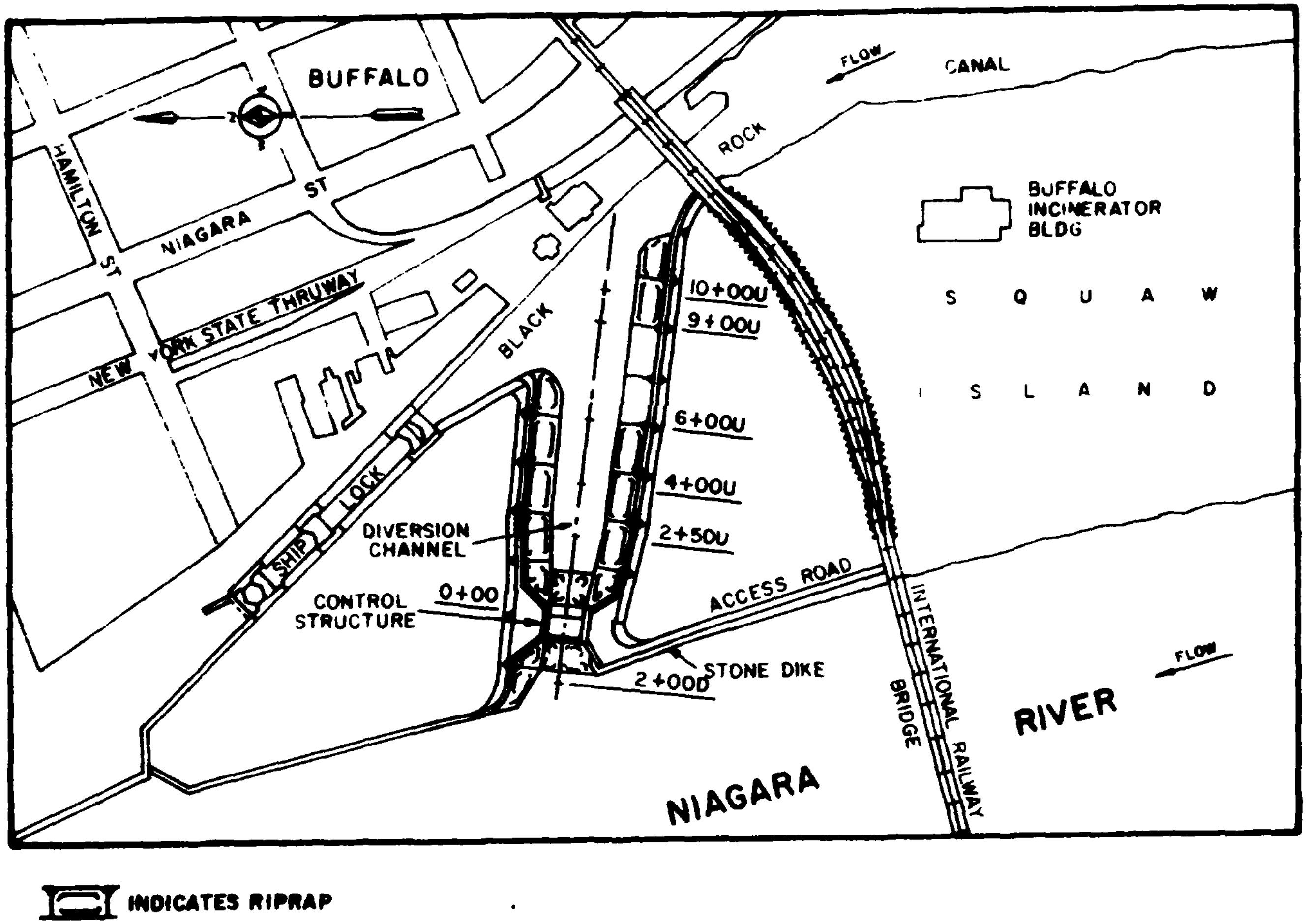
PLAN SI - 30' GATE

FIGURE B-20



BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE SI
PLAN SI - 75' GATE

FIGURE B-21

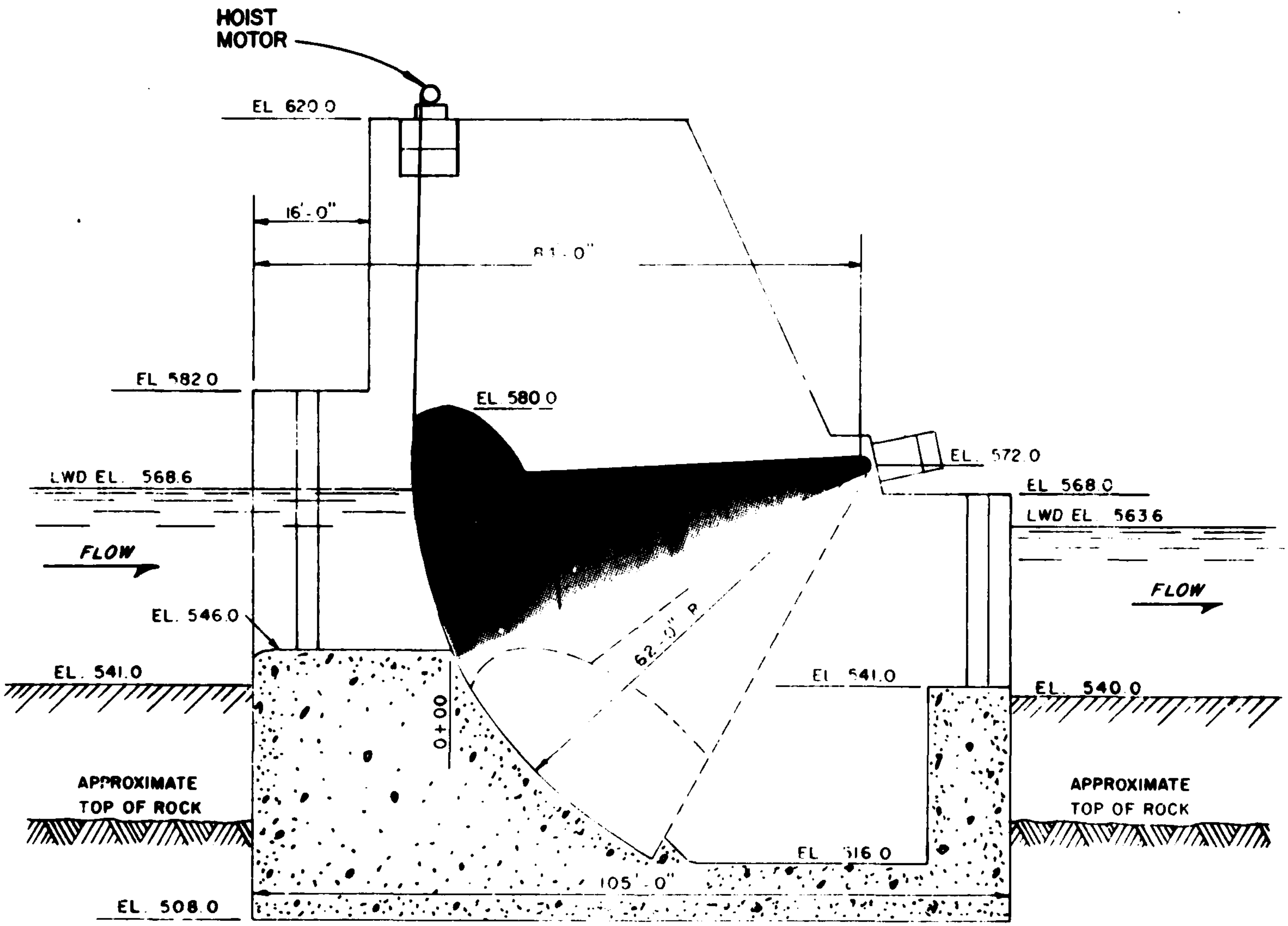


BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S1

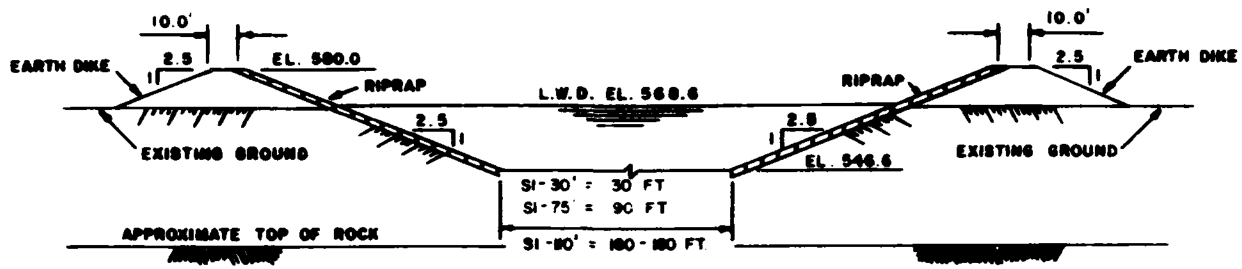
PLAN S1 - 110' GATE

FIGURE B-22

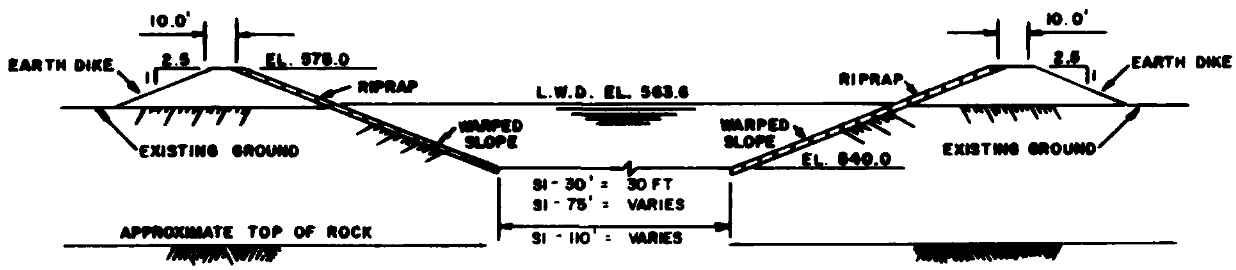


BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE S1
CENTERLINE PROFILE OF CONTROL STRUCTURE

FIGURE B-23



TYPICAL SECTION OF DIVERSION CHANNEL
UPSTREAM OF CONTROL STRUCTURE



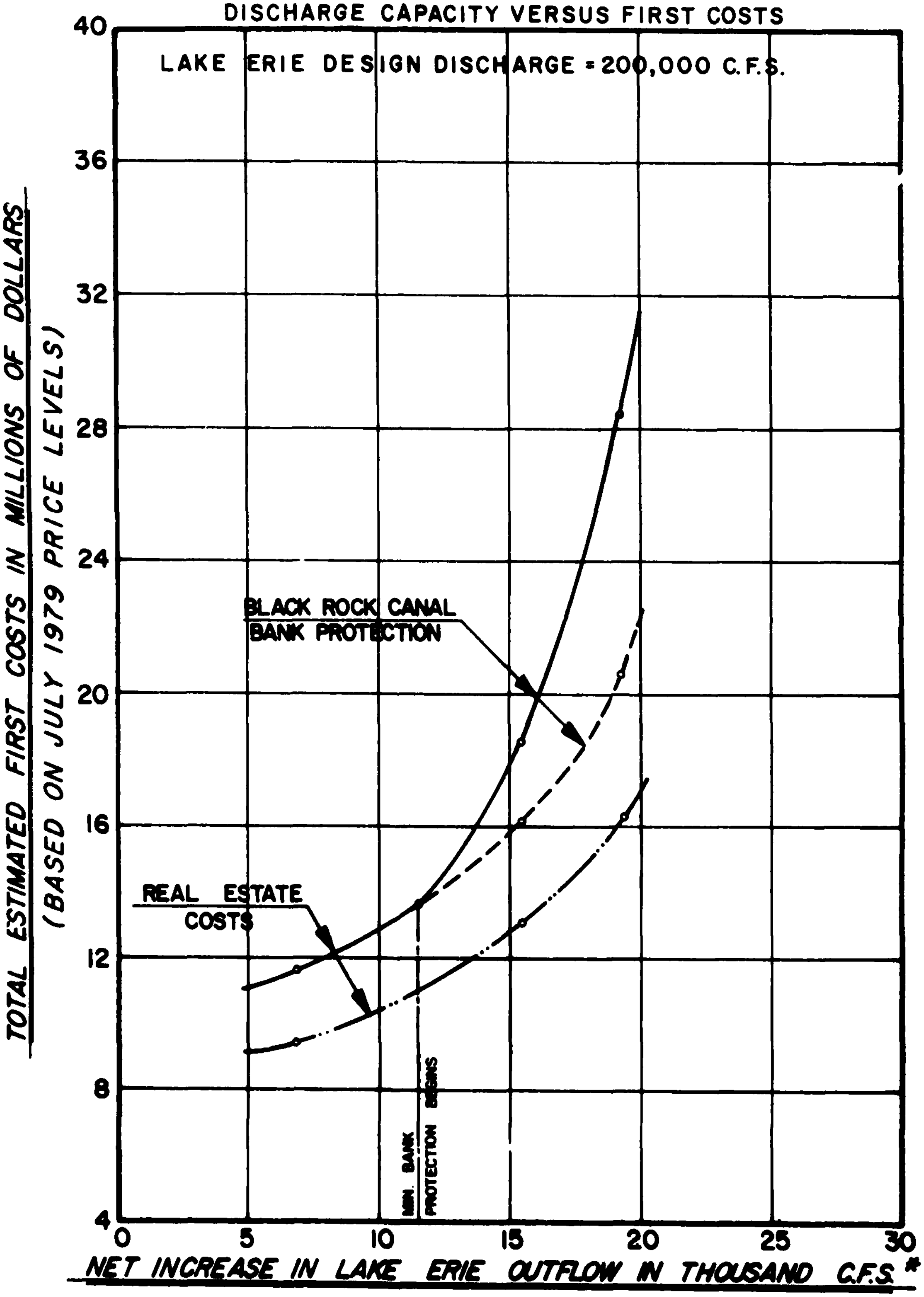
TYPICAL SECTION OF DIVERSION CHANNEL
DOWNSTREAM OF CONTROL STRUCTURE

BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE SI

CROSS SECTIONS OF DIVERSION CHANNEL

FIGURE B-24

BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE S1
DISCHARGE CAPACITY VERSUS FIRST COSTS



*WITHOUT OPERATING CONSTRAINTS

FIGURE B-25

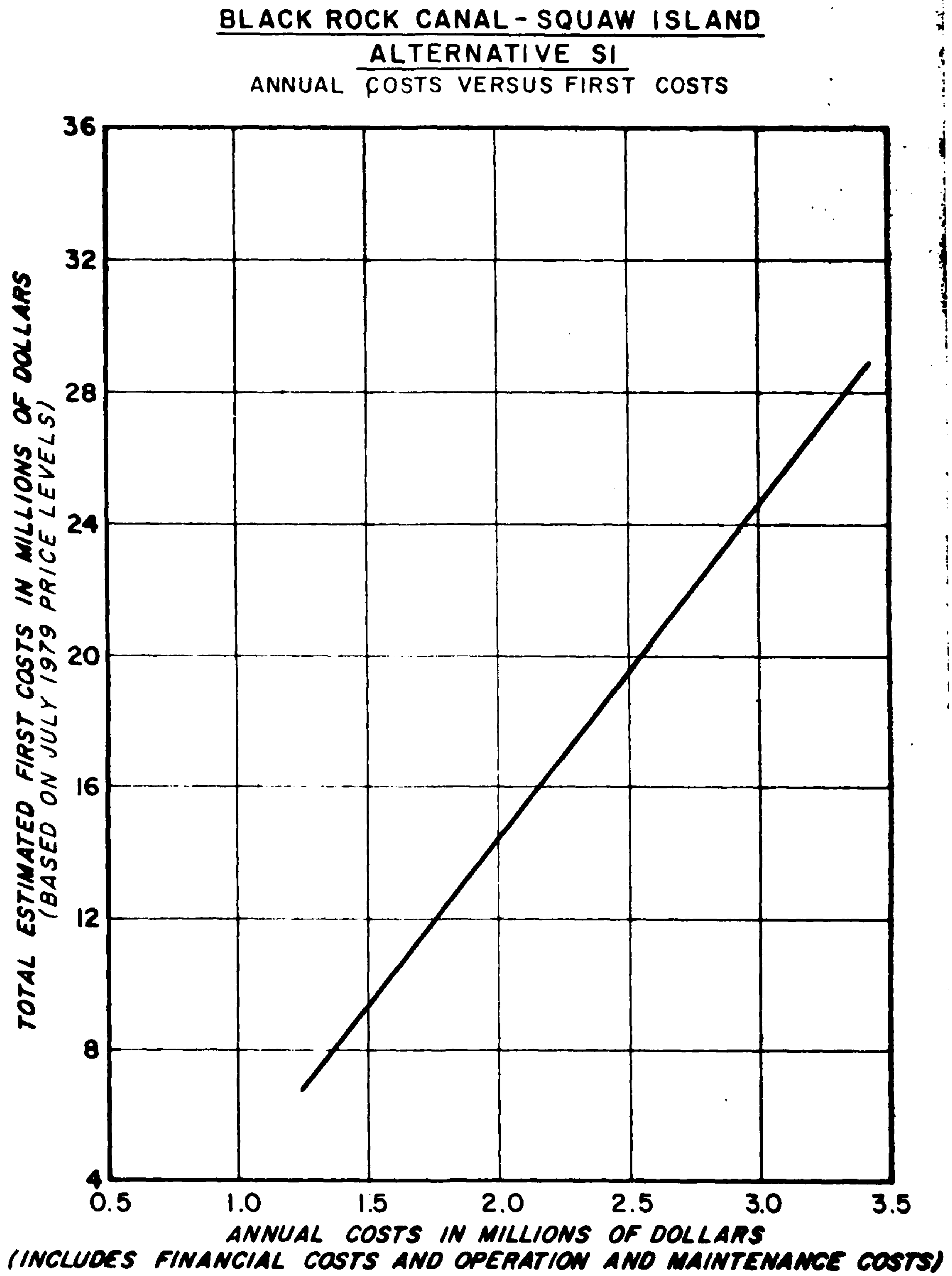
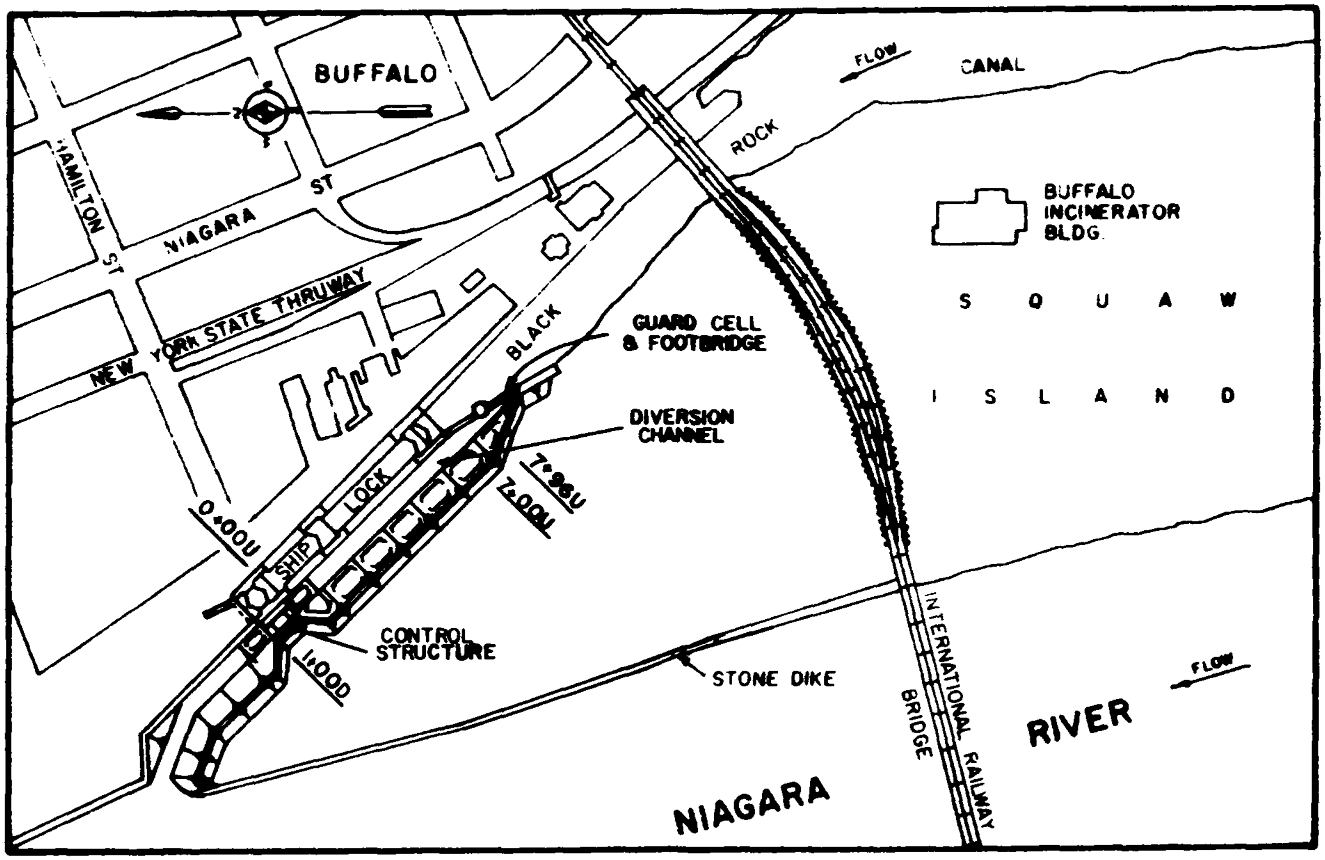

BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE SI
ANNUAL COSTS VERSUS FIRST COSTS
36
32
28
24
20
16
12
8
4
TOTAL ESTIMATED FIRST COSTS IN MILLIONS OF DOLLARS
(BASED ON JULY 1979 PRICE LEVELS)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
ANNUAL COSTS IN MILLIONS OF DOLLARS
(INCLUDES FINANCIAL COSTS AND OPERATION AND MAINTENANCE COSTS)

FIGURE B-26



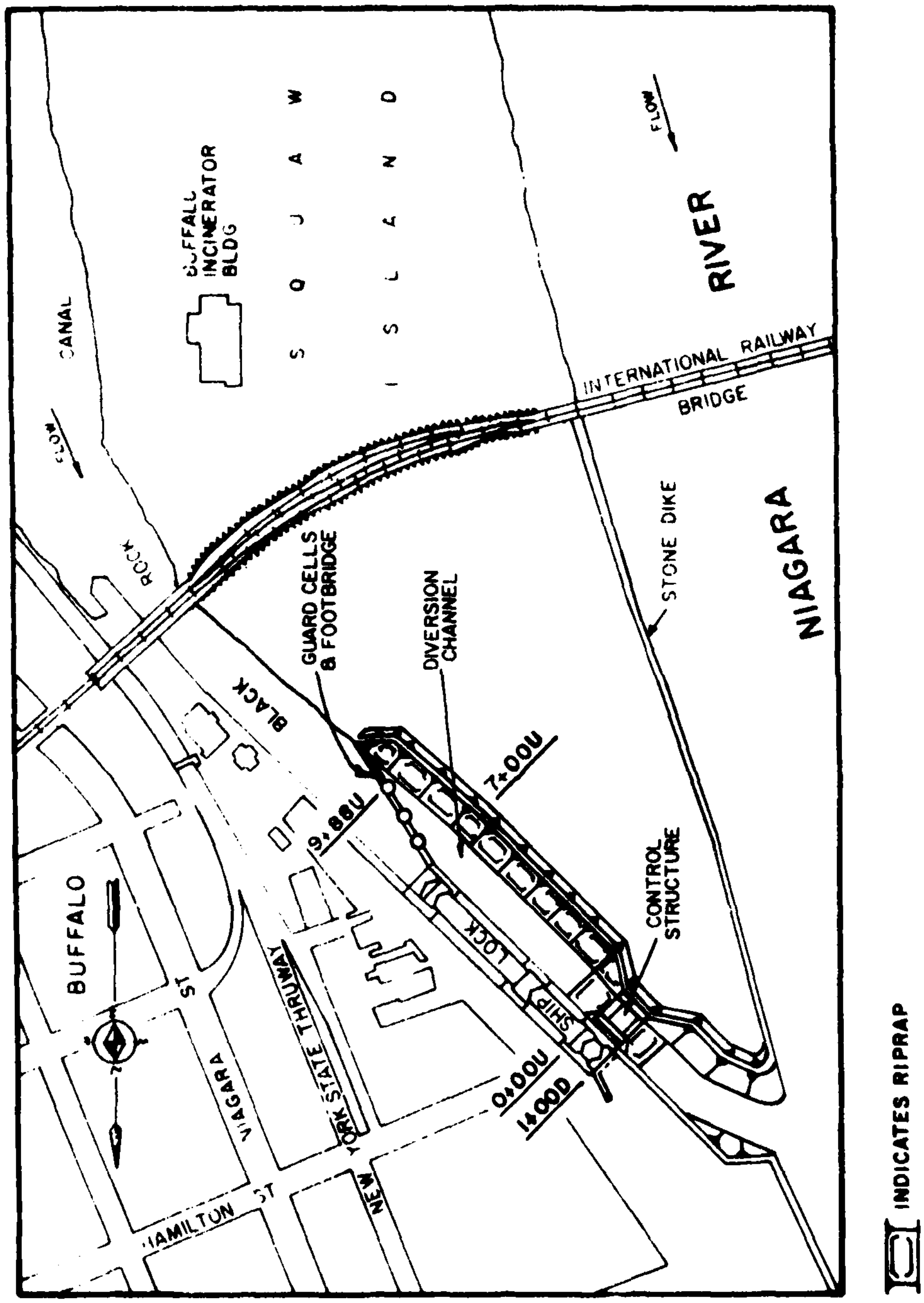
INDICATES RIPRAP

BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S2

PLAN S2 - 30' GATE

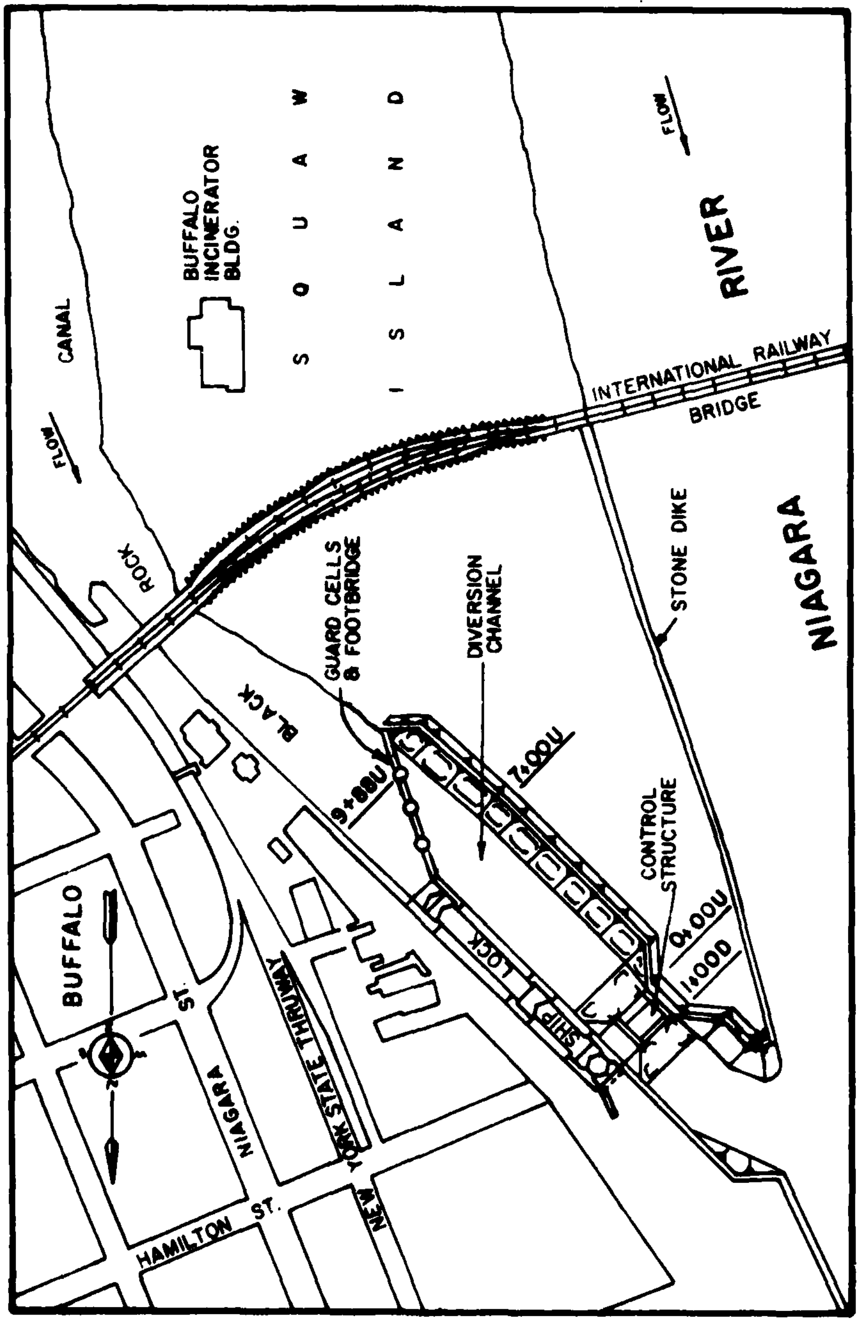
FIGURE B-27



BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S2

PLAN S2 - 75' GATE



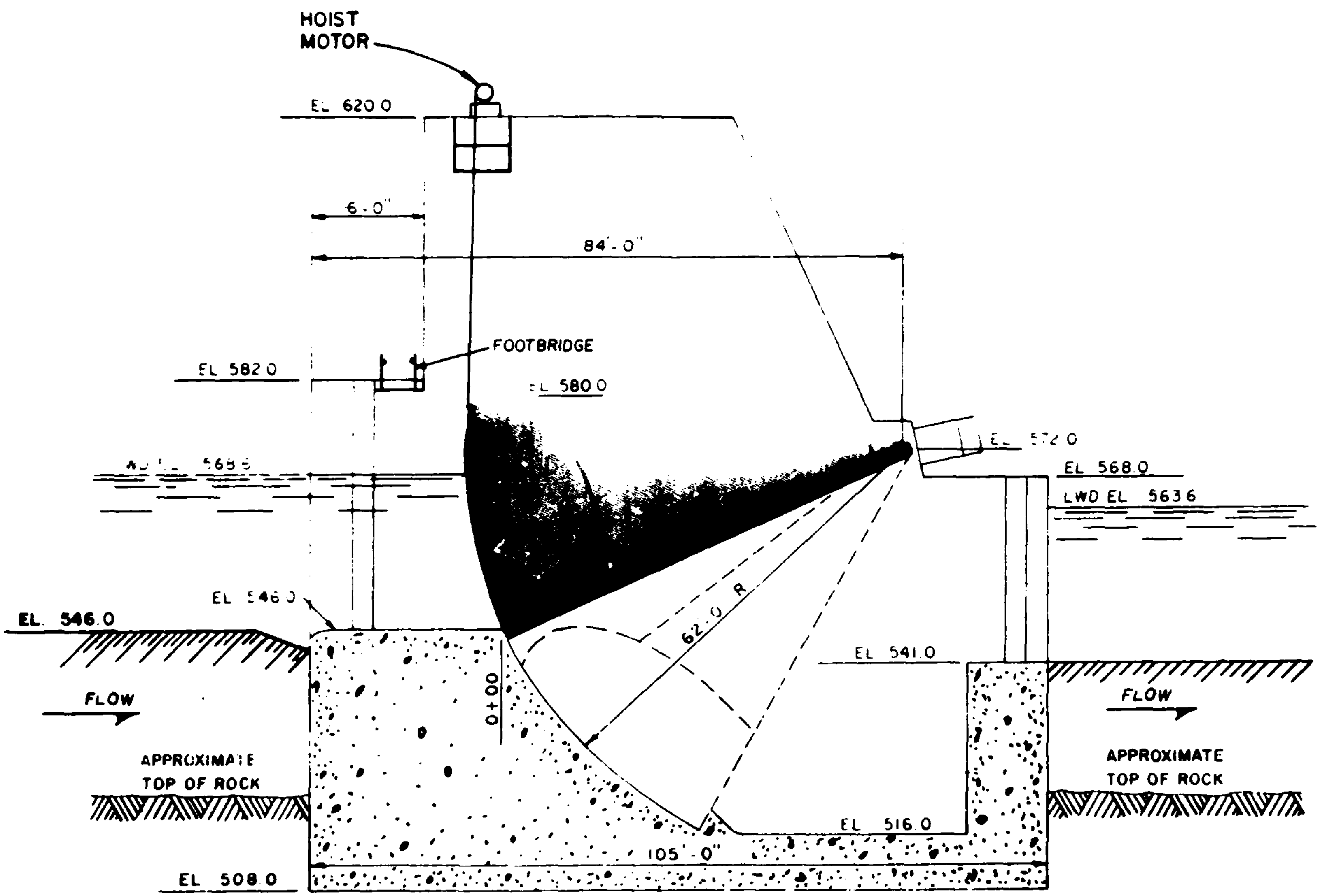
INDICATES RIPRAP

BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S2

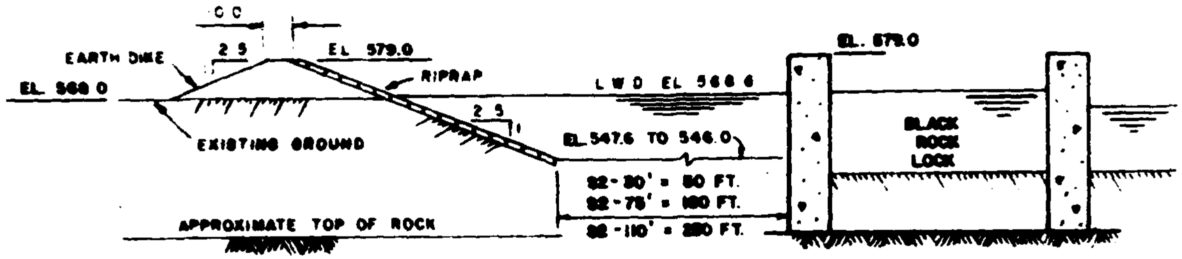
PLAN S2 - 110' GATE

FIGURE B-29

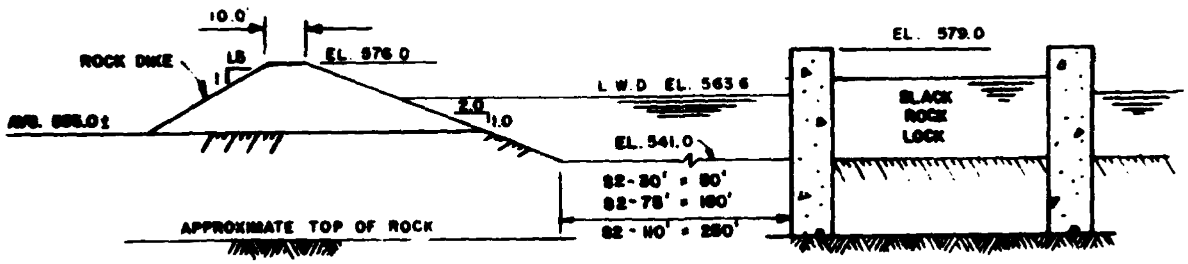


BLACK ROCK CANAL SQUAW ISLAND
ALTERNATIVE S2
CENTERLINE PROFILE OF CONTROL STRUCTURE

FIGURE B-30



TYPICAL SECTION OF DIVERSION CHANNEL
UPSTREAM OF CONTROL STRUCTURE



TYPICAL SECTION OF DIVERSION CHANNEL
DOWNSTREAM OF CONTROL STRUCTURE

BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S2

CROSS SECTIONS OF DIVERSION CHANNEL

FIGURE B-31

The maximum increased discharge capacity of Alternative S2 without Black Rock Canal operating constraints varies from 6,800 cubic feet per second for a 30-foot gate structure to 19,200 cubic feet per second for a 110-foot gate structure. Capacity reductions, similar to Alternative S1, would be required and based on the operating plan shown on Figure B-9. The corresponding reduced capacities for Alternative S2 would vary from 4,250 to 12,000 cubic feet per second. The first costs of the control structure, diversion channel, and appurtenant works would range from approximately $11.2 to $32.0 million. A discharge capacity versus first cost curve for Alternative S2 is shown on Figure B-32 for a Lake Erie design discharge of 200,000 cubic feet per second. Corresponding annual costs, after adjustments for finance, operation, and maintenance costs, are estimated to range from $1.2 to $3.2 million. Figure B-33 shows a first cost versus annual cost curve for Alternative S2. Discharge capacities and a cost summary, including first costs, annual costs, and present worth, are shown in Table B-2.

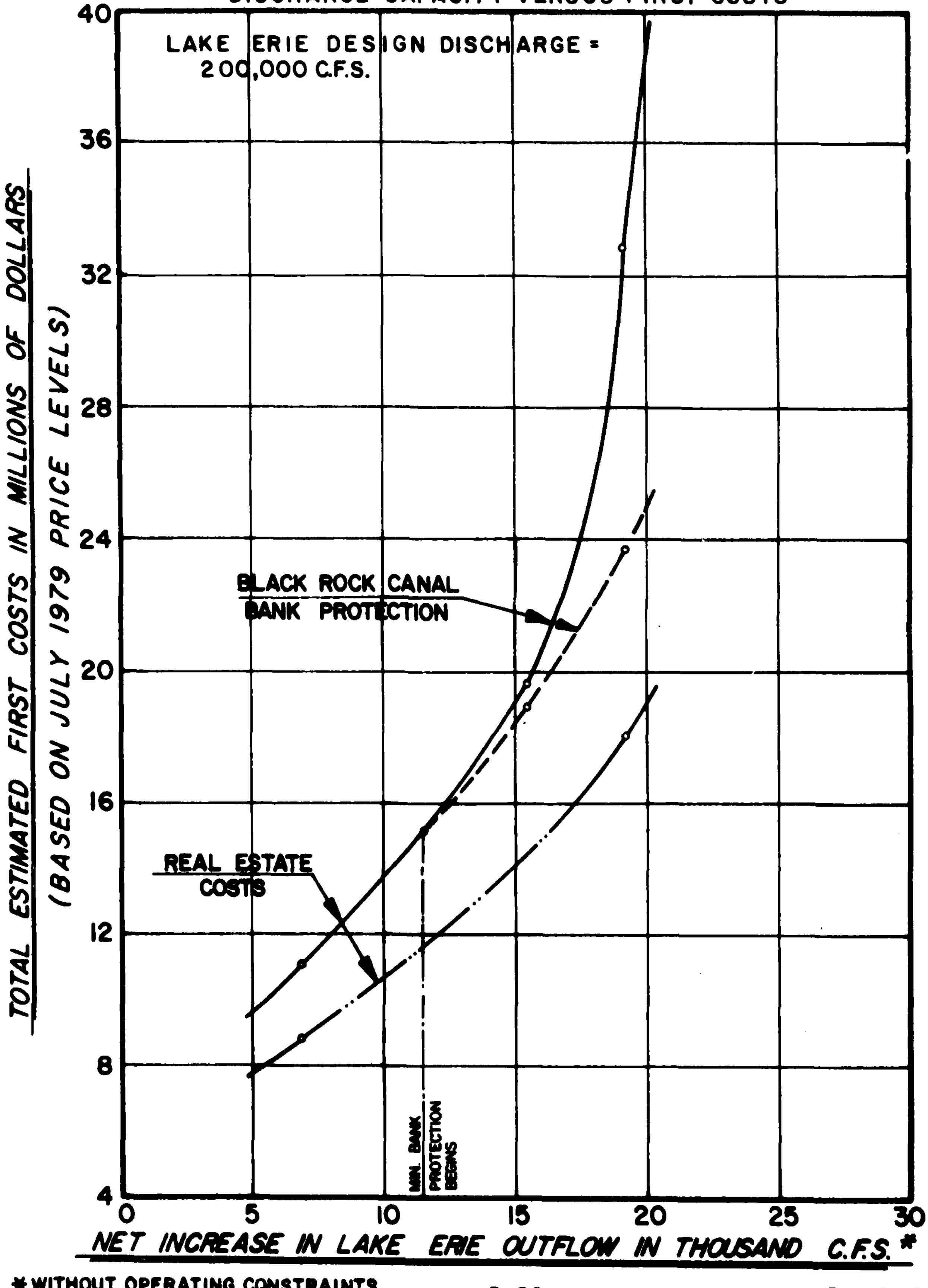
2.6.4 Alternative S3

Alternative S3 would require construction of a control structure at the upstream end of Squaw Island along the alignment of the Bird Island Pier. In addition, bank protection would be required at critical locations along the Black Rock Canal, as necessary. A discharge capacity versus first cost curve was developed for a range of regulation plans based on three variations of control structure size.

The control structure would replace a section of the existing Bird Island Pier immediately adjacent to the upstream end of Squaw Island. The structure would contain one to three remote-controlled submersible tainter gates, 23 feet high by 90 feet wide. The entire structure would be equipped for year-round operation. The number of control gates would vary to accommodate different regulation plans. Construction of the structure would require extensive cofferdams to be located in both the Black Rock Canal and the Niagara River. An enclosed foot bridge would be provided at the control structure to maintain public access to the Bird Island Pier. Bank protection along the Black Rock Canal would be provided upstream of the control structure in high velocity reaches dependent upon the stability of the existing sideslopes and/or structures. A traffic control system for commercial navigation would be provided similar to the Alternative S1 facilities. In addition, movable floating log booms would be utilized in the canal to prevent recreational navigation from entering dangerous waters around the control structure during periods of diversion flows. Descriptive plans of the three Alternative S3 variations and a longitudinal section through the control structure are shown on Figures B-34 through B-37, respectively.

The maximum increased discharge capacity of Alternative S3 without Black Rock Canal operating constraints varies from 6,200 cubic feet per second for a one-gate structure to 15,300 cubic feet per second for a three-gate structure. Capacity reductions, similar to Alternative S1, would be required and based on the operating plan shown on Figure B-9. The corresponding reduced capacities for Alternative S3 would vary from 3,870 to 9,560 cubic feet per second. The first cost of the control structure and appurtenant works would range from approximately $10.2 to $26.1 million. A discharge

BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE S2
DISCHARGE CAPACITY VERSUS FIRST COSTS



* WITHOUT OPERATING CONSTRAINTS

FIGURE B-32

BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S2

ANNUAL COSTS VERSUS FIRST COSTS

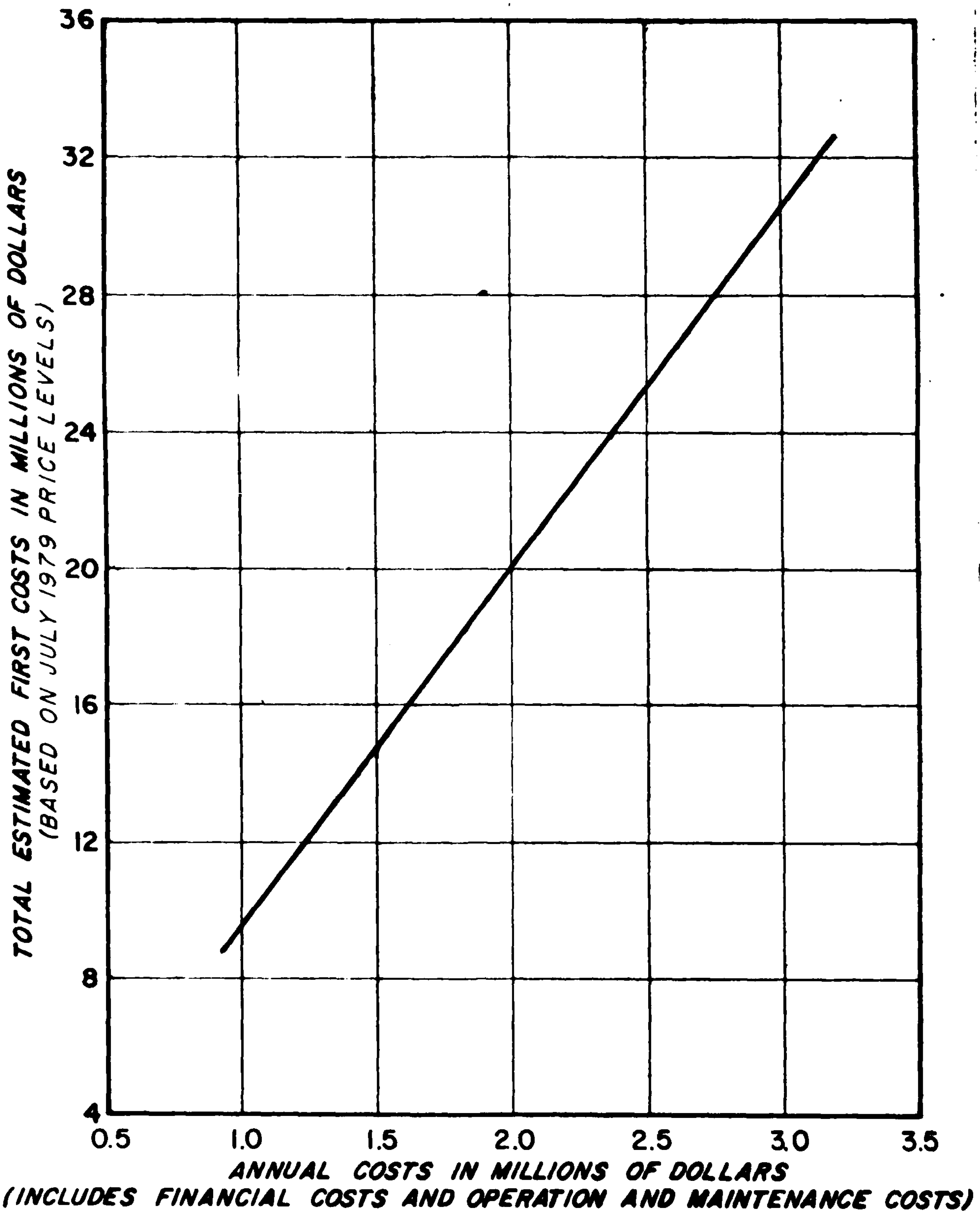
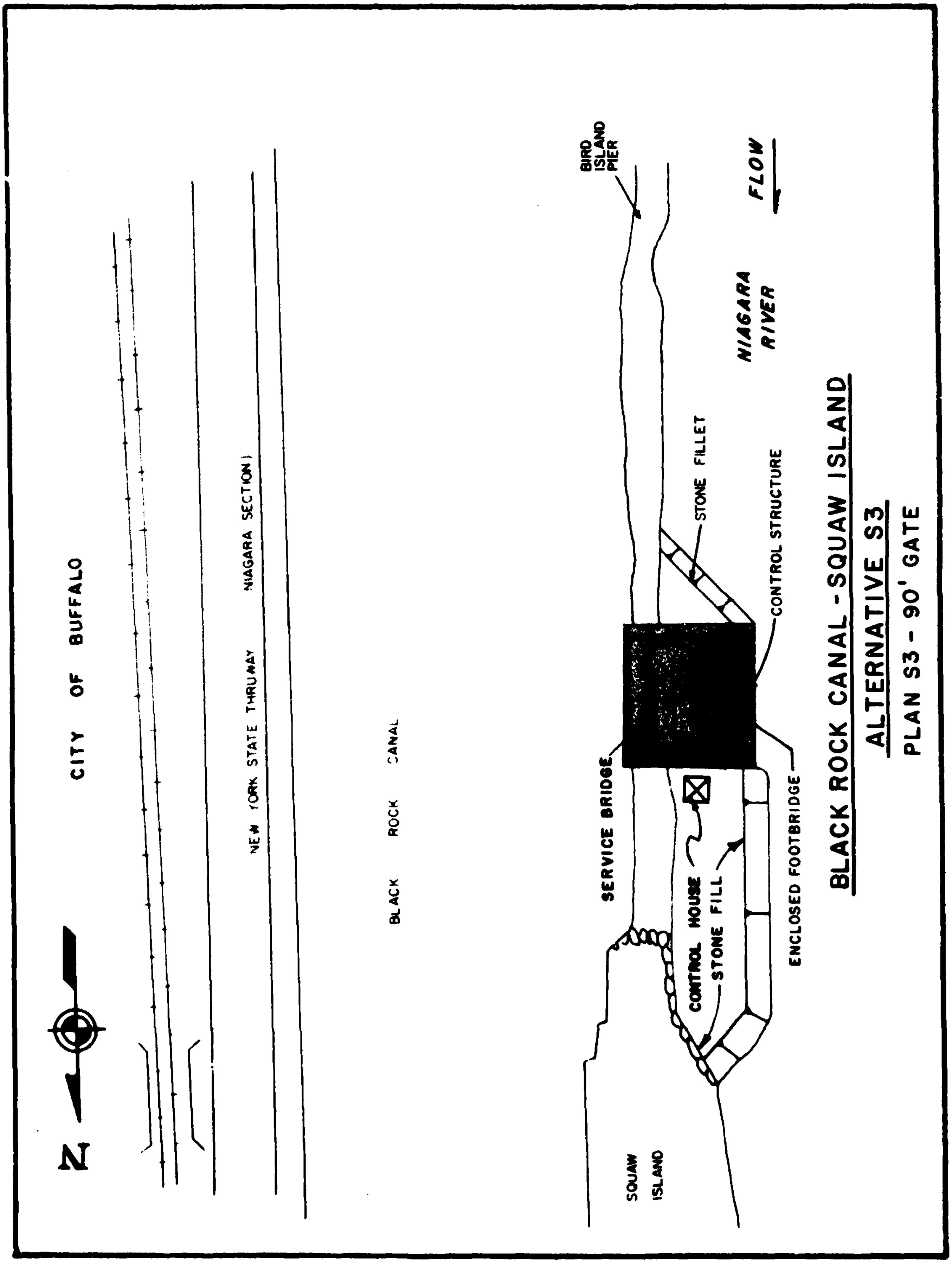


FIGURE B-33

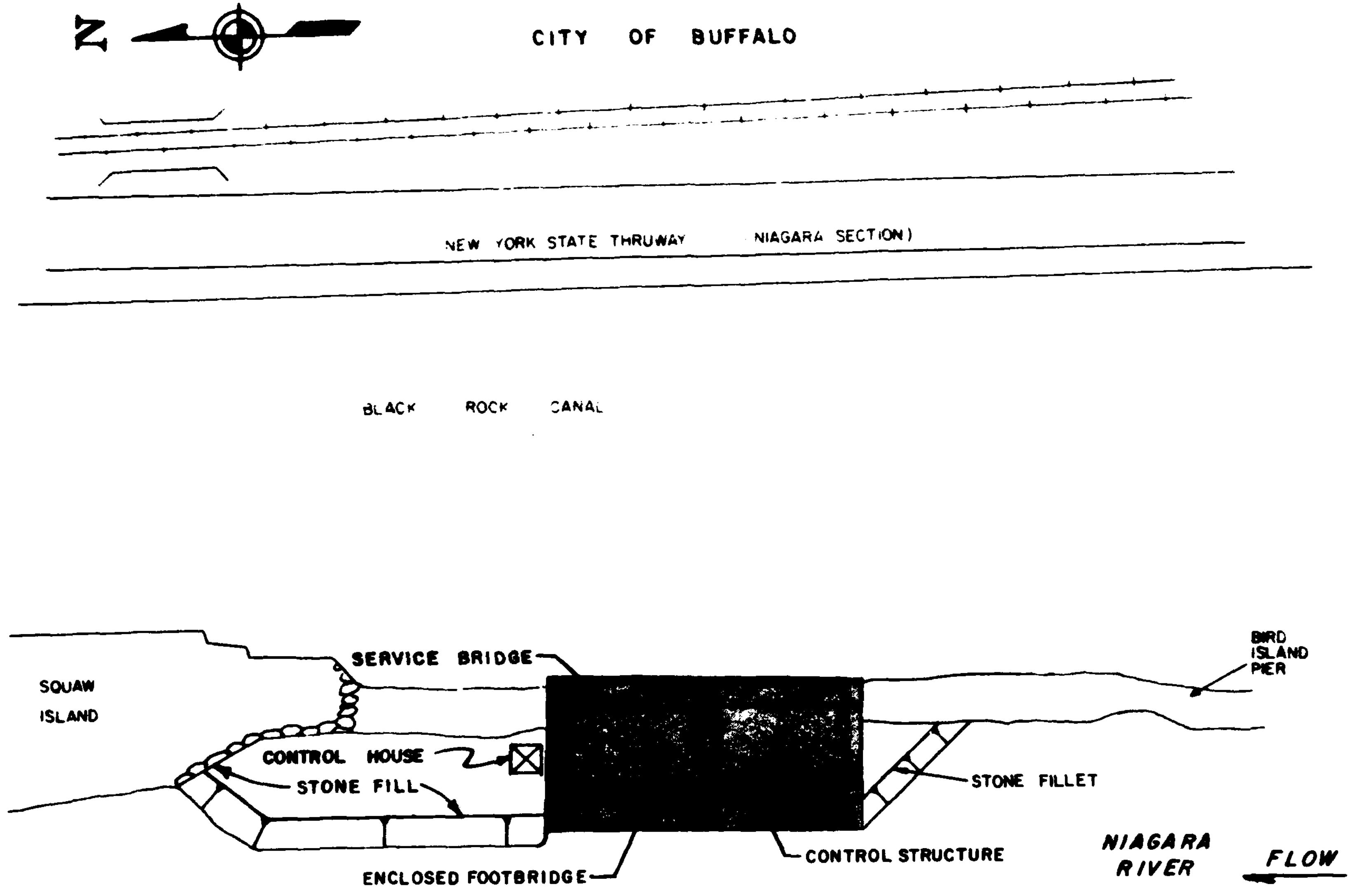


BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S3

PLAN S3 - 90' GATE

FIGURE B-34



BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S3

PLAN S3 - 90' GATE (2)

FIGURE B-35

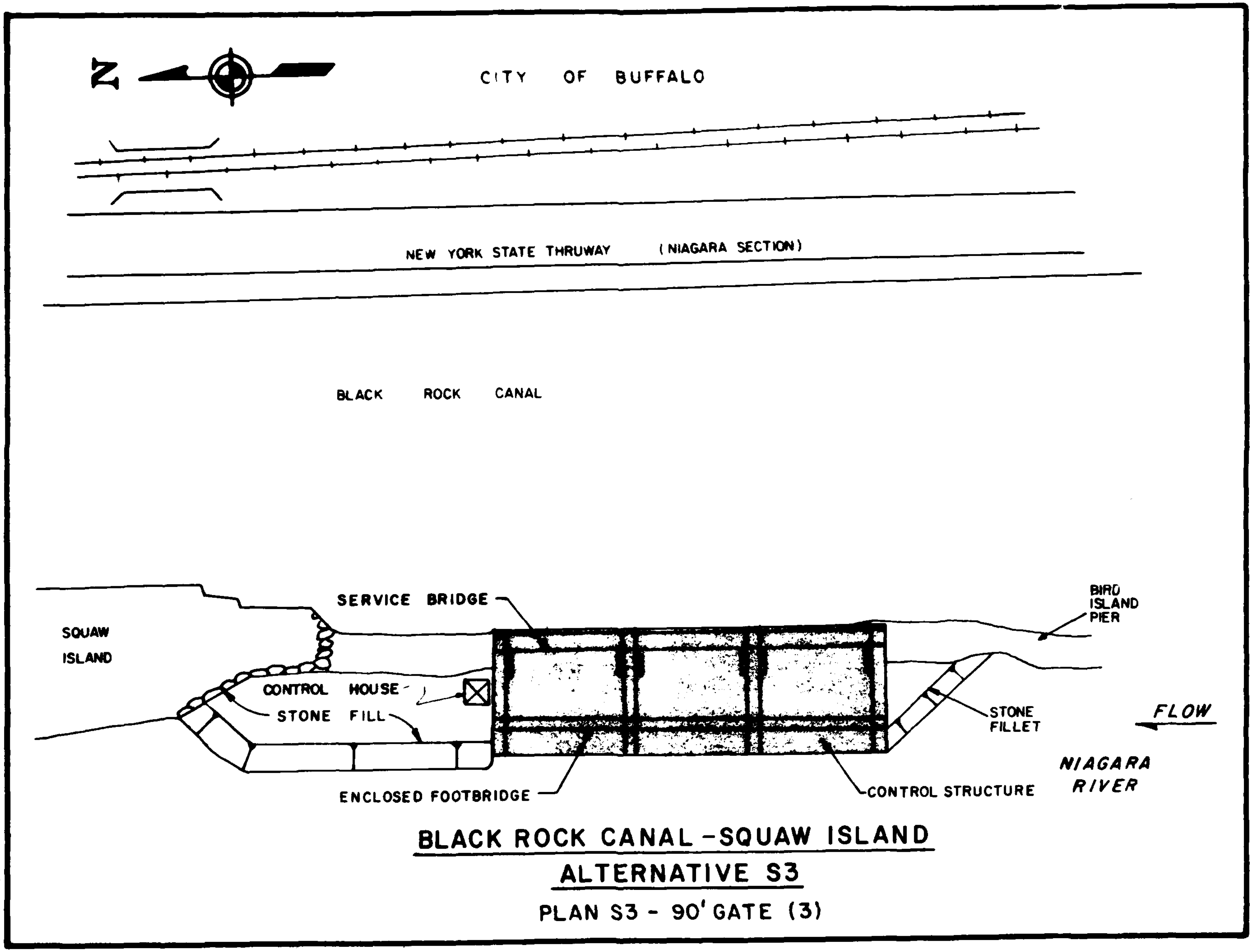
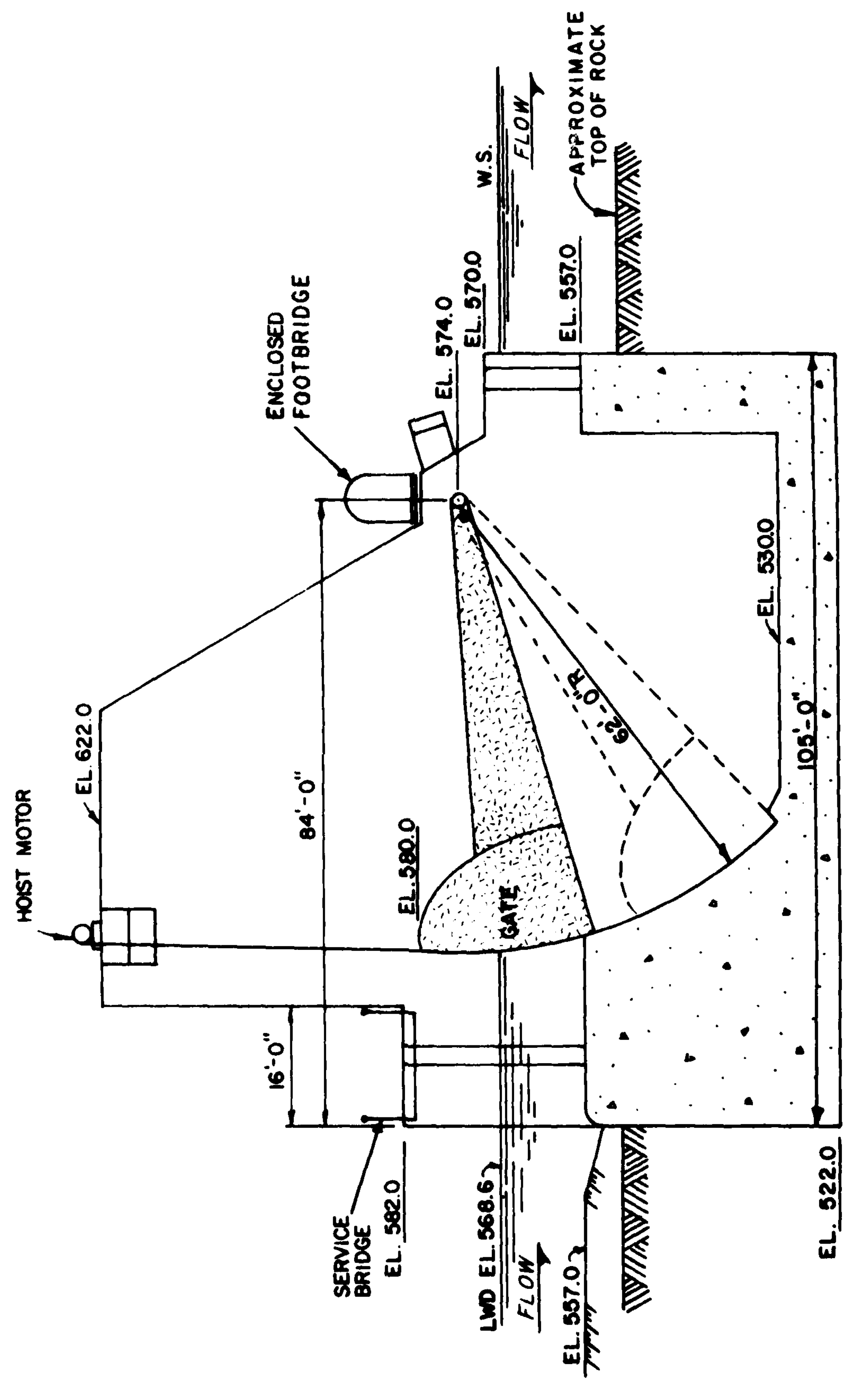

N
CITY OF BUFFALO
NEW YORK STATE THRUWAY (NIAGARA SECTION)
BLACK ROCK CANAL
SQUAW ISLAND
SERVICE BRIDGE
CONTROL HOUSE
STONE FILL
ENCLOSED FOOTBRIDGE
CONTROL STRUCTURE
STONE FILLET
BIRD ISLAND PIER
FLOW
NIAGARA RIVER
BLACK ROCK CANAL - SQUAW ISLAND
ALTERNATIVE S3
PLAN S3 - 90' GATE (3)

FIGURE B-36



BLACK ROCK CANAL—SQUAW ISLAND

ALTERNATIVE S3

CENTERLINE PROFILE OF CONTROL STRUCTURE

FIGURE B-37

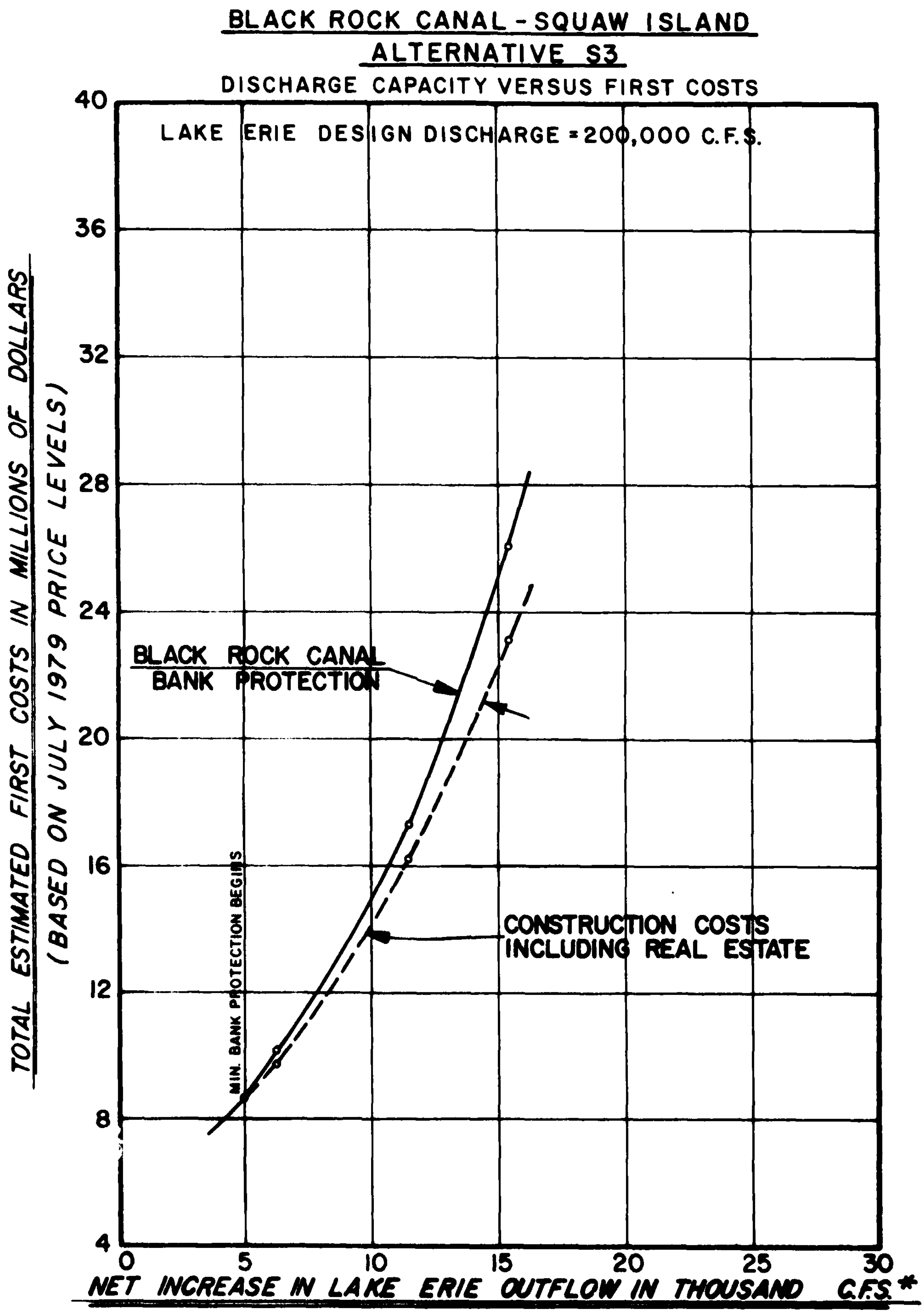
capacity versus first cost curve for Alternative S3 is shown on Figure B-38 for a Lake Erie design discharge of 200,000 cubic feet per second. Corresponding annual costs, after adjustments for finance, operation and maintenance costs, are estimated to range from $1.2 to $2.8 million. Figure B-39 shows a first cost versus annual cost curve for Alternative S3. Discharge capacities and a cost summary, including first costs, annual costs, and present worth are shown in Table B-2.

2.6.5 Alternative L1

Alternative L1 would require modification of the existing Black Rock Lock by the addition of a control structure, consisting of a pair of sector gates. In addition, bank protection would be required at critical locations along the Black Rock Canal, as necessary. Since dimensional modification of the lock chamber is not permissible, the maximum discharge capacity of this alternative is limited. Two variations of gate operation were studied to develop a discharge capacity versus first cost curve to accommodate a range of regulation plans.

A control structure, consisting of a pair of hydraulically operated sector gates, would be constructed in the upstream approach channel adjacent to the existing upper-guard gate. In a closed position, the 33-foot sector gates would span the 70-foot wide lock chamber. They would rotate horizontally into recesses to provide varying discharge capacities when the lock was out of operation. During periods set aside for navigation, the sector gates would recess flush into the chamber walls. The open width of the sector gates would vary to accommodate different regulation plans. The entire structure would be equipped for year-round operation. Bank protection along the Black Rock Canal and a traffic control system would be provided similar to the Alternative S1 facilities. A prefabricated and reusable cofferdam system would be utilized across the Black Rock Canal to permit staged construction over several winters in order to accommodate regular summer navigation. A descriptive plan of the required lock modifications and a transverse section through the control structure are shown on Figures B-40 and B-41.

The maximum increased discharge capacity of Alternative L1 without Black Rock Canal operating constraints varies from 6,800 cubic feet per second for a 30-foot open gate to 16,000 cubic feet per second for a 70-foot open gate. Capacity reductions, similar to Alternative S1, would be required and based on the operating plan shown on Figure B-10. The corresponding reduced capacities for Alternative L1 would vary from 3,680 to 8,670 cubic feet per second. The first costs of the control structure and appurtenant works would range from approximately $10.3 to $13.1 million. A discharge capacity versus first cost curve for Alternative L1 is shown on Figure B-42 for a Lake Erie design discharge of 200,000 cubic feet per second. Corresponding annual costs, after adjustments for finance, operation and maintenance costs, are estimated to range from $1.2 to $1.5 million. Figure B-43 shows a first cost versus annual cost curve for Alternative L1. Discharge capacities and a cost summary, including first costs, annual costs, and present worth are shown in Table B-2.



*WITHOUT OPERATING CONSTRAINTS

FIGURE B-38

BLACK ROCK CANAL - SQUAW ISLAND

ALTERNATIVE S3

ANNUAL COSTS VERSUS FIRST COSTS

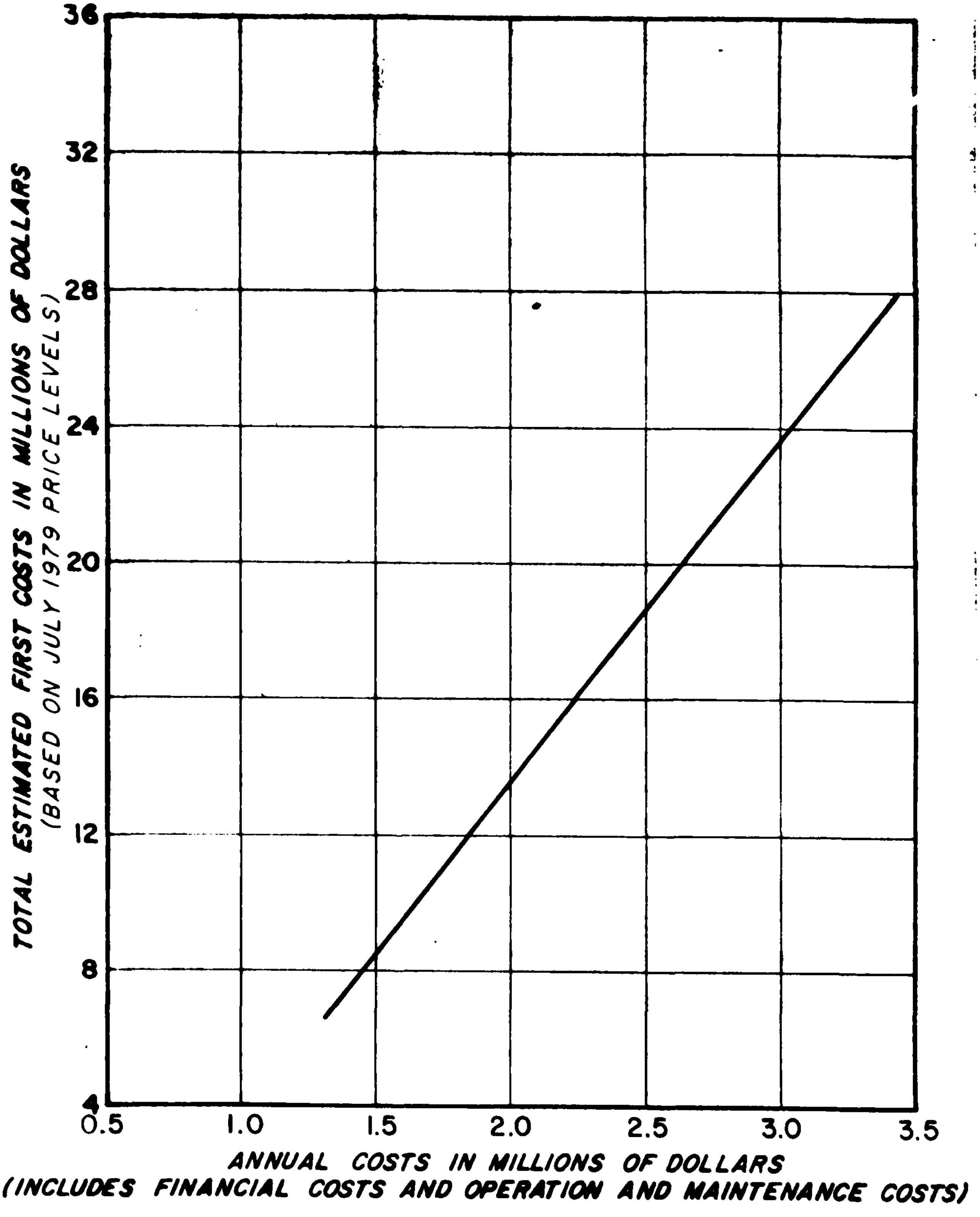
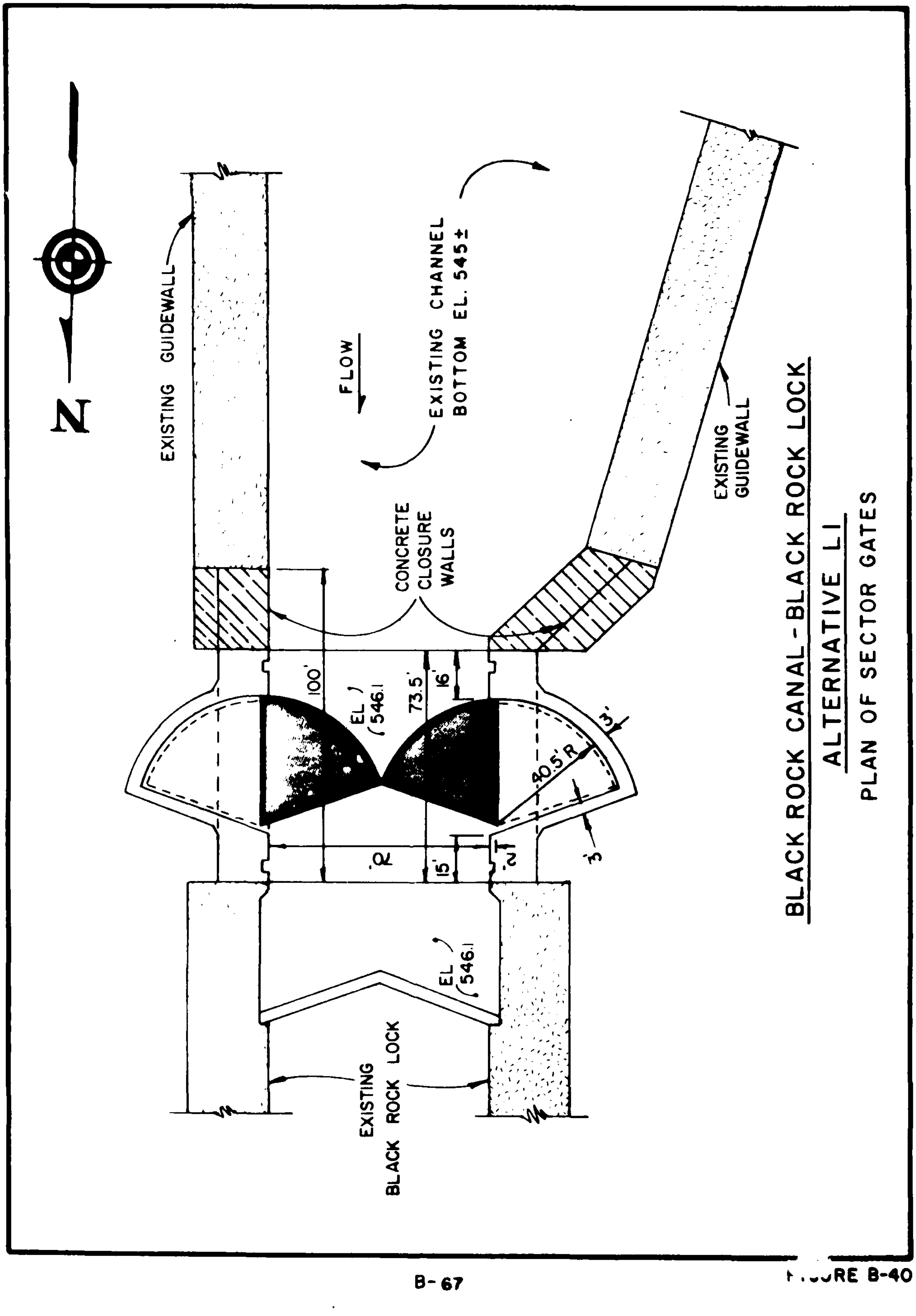


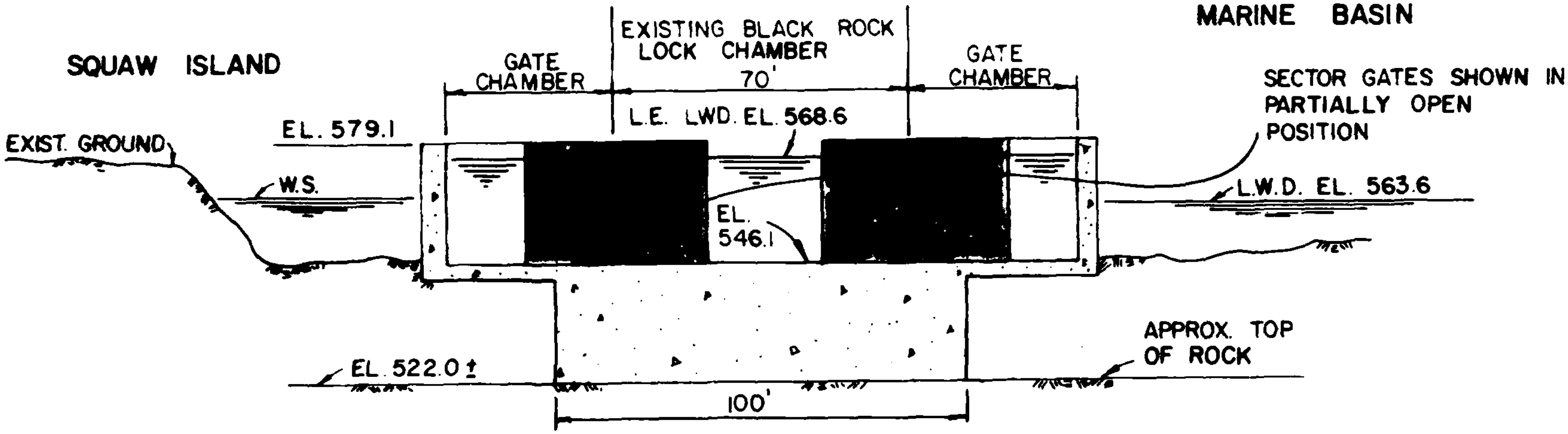
FIGURE B-39



BLACK ROCK CANAL - BLACK ROCK LOCK

ALTERNATIVE L1

PLAN OF SECTOR GATES



BLACK ROCK CANAL - BLACK ROCK LOCK

ALTERNATIVE L1

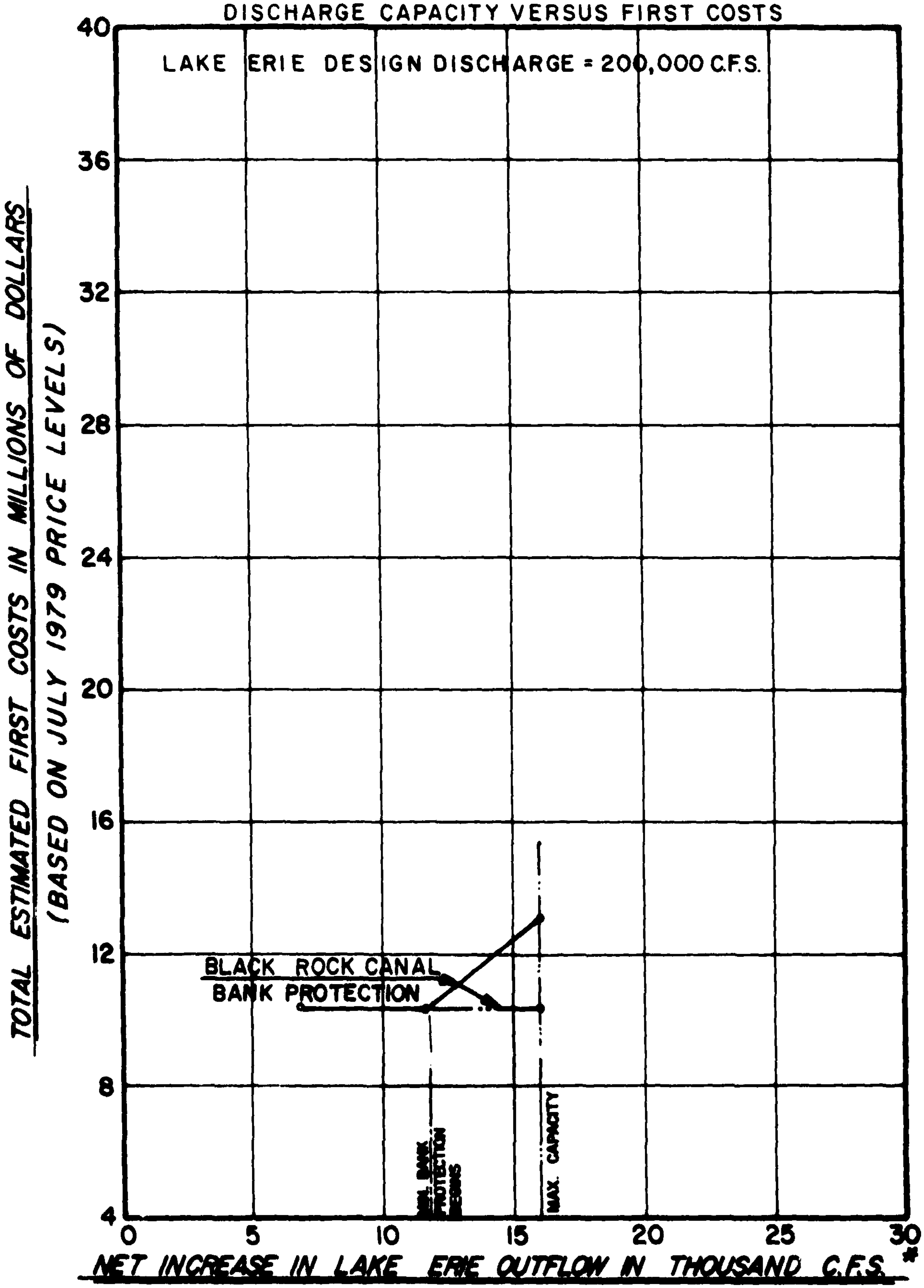
CROSS SECTION OF SECTOR GATES

FIGURE B-41

BLACK ROCK CANAL - BLACK ROCK LOCK

ALTERNATIVE LI

DISCHARGE CAPACITY VERSUS FIRST COSTS



*WITHOUT OPERATING CONSTRAINTS

FIGURE B-42

BLACK ROCK CANAL - BLACK ROCK LOCK
ALTERNATIVE L1
ANNUAL COSTS VERSUS FIRST COSTS

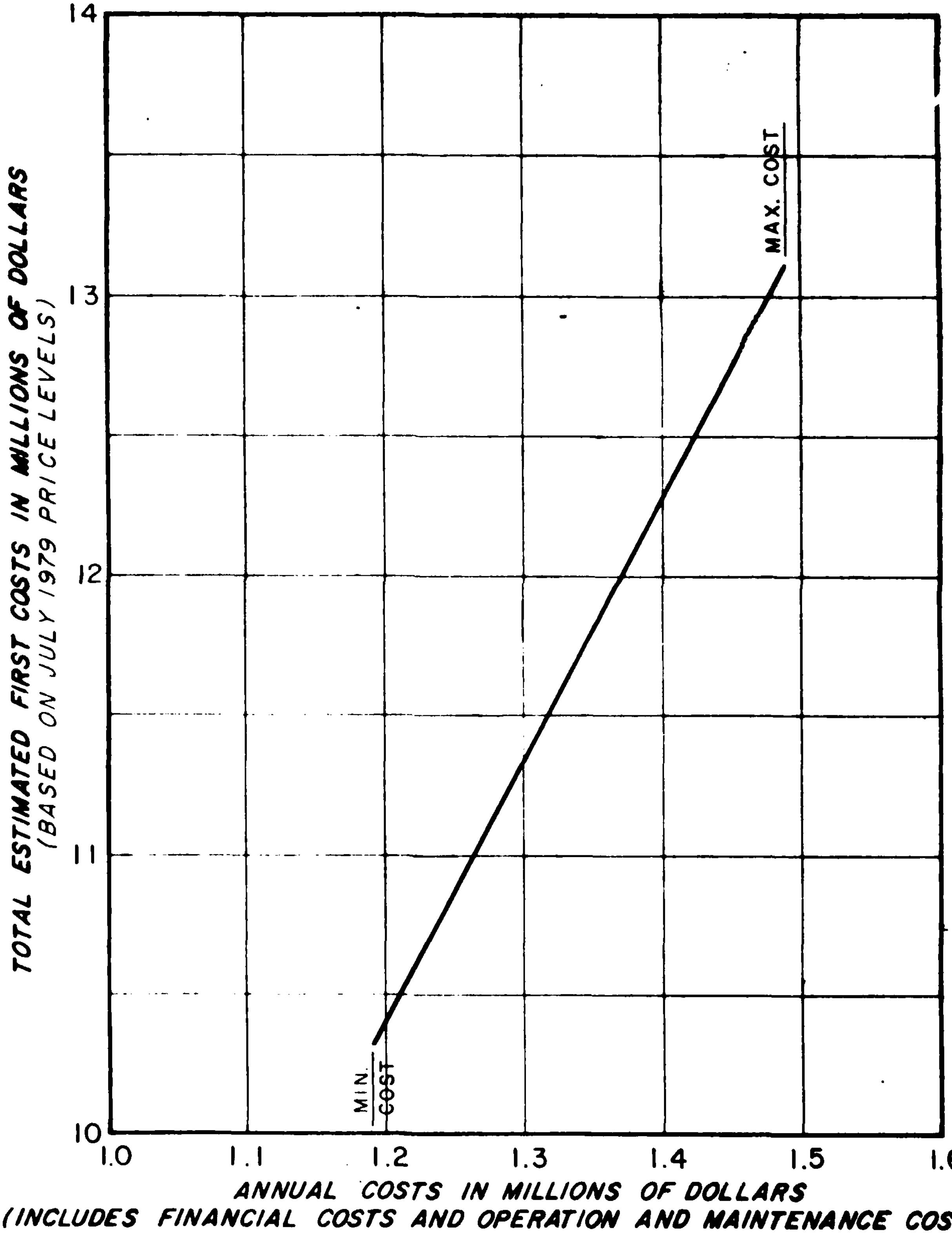


FIGURE B-43

2.7 Structural Works Required for Selected Regulation Plans

A series of Lake Erie regulation plans were developed to study a range of increases in Lake Erie outflow that would provide limited regulation of Lake Erie during periods of high supply. Each plan would require construction of regulatory works and remedial measures at the head of the Niagara River. Three of these regulation plans were selected to represent high-range, mid-range, and low-range increases in lake outflow at the critical Lake Erie design discharge of 200,000 cubic feet per second. Each selected plan was evaluated with respect to the regulatory works alternatives discussed in Section 2.6. The following is a summary of the regulatory works and remedial measures that would best implement each of the selected plans while satisfying economic criteria.

2.7.1 Regulation Plan 25N

Plan 25N addresses a high-range regulation plan that would provide an approximate increase in Lake Erie design outflow of 25,000 cubic feet per second. Of the five structural alternatives, under study, only Alternative N3 could provide high-range increases in lake outflow. Least cost implementation of Plan 25N would be achieved with a six-gate variation of Alternative N3. This variation would provide the required 25,000 cubic feet per second design outflow. Since operating constraints are not required with a series "N" alternative, the net increase in lake outflow would equal the design outflow. The greatest effective lowering of Lake Erie versus average annual cost for a high range increase in lake outflow would be achieved with this plan.

The location of Alternative N3 and the regulatory works and remedial measures required to implement Plan 25N are discussed in Section 2.6.1. Figure B-15 in Section 2.6.1 shows the location of the proposed control structure and the limits of compensatory dredging. Figure B-17 shows a longitudinal cross section through the control structure. The total first cost of this control structure, compensatory dredging and appurtenant works, based on July 1979 price levels is approximately $111.4 million. The corresponding annual cost, after adjustments for finance, operation and maintenance costs, is estimated to be $11.6 million. Table B-4 shows a time profile of all undiscounted and discounted project costs in each year of occurrence over the assumed 50-year economic project life. The present worth of all project costs is approximately $134.3 million.

Table B-4 - Regulation Plan 25N - Project Cost Time Profile

Item	Year	Undiscounted Project Cost[1]	Discounted Project Cost[1]
		$	$
Investment Cost		130,331,000	130,331,000
Operation and Maintenance Cost	1	339,000	312,442
			287,965
			265,406
			244,614
Operation and Maintenance Cost	5	339,000	225,450
			207,788
			191,510
			176,507
			162,679
Operation and Maintenance Cost	10	339,000	149,935
			138,189
			127,363
			117,385
			108,189
Operation and Maintenance Cost	15	339,000	99,713
			91,902
			84,702
			78,066
			71,951
Operation and Maintenance Cost	20	339,000	66,314
			61,119
			56,331
			51,918
			47,850
Operation and Maintenance Cost	25	339,000	44,102
			40,647
			37,463
			34,528
			31,823
Operation and Maintenance Cost	30	339,000	29,330
			27,032
			24,914
			22,962
			21,164
Operation and Maintenance Cost	35	339,000	19,506
			17,977
			16,569
			15,271
			14,075
Operation and Maintenance Cost	40	339,000	12,972
			11,956
			11,014
			10,156
			9,360
Operation and Maintenance Cost	45	339,000	8,627
			7,951
			7,328
			6,754
			6,225
Operation and Maintenance Cost	50	339,000	5,737
Present Worth			134,251,736

1/ Cost estimates are based on July 1979 price levels, 50-year economic project life and an 8-1/2 percent interest rate.

2.7.2 Regulation Plan 15S

Plan 15S addresses a mid-range regulation plan that would provide an approximate increase in Lake Erie design outflow of 15,000 cubic feet per second. All five structural alternatives, under study, could provide mid-range increases in lake outflow. Alternatives N3 and S3 were eliminated for economic reasons. Least cost implementation of Plan 15S could be achieved with either alternatives L1 or S1. However, engineering feasibility and future environmental and social concerns require selection of Alternative S2. The implementation of Plan 15S would best be achieved with a 75-foot wide gate variation of alternative S2. This variation would provide an increase in Lake Erie design outflow of 15,400 cubic feet per second. Operational constraints in the Black Rock Canal would reduce the design outflow to a net increase in lake outflow of 9,620 cubic feet per second.

The location of alternative S2 and the regulatory works and remedial measures required to implement Plan 15S are discussed in Section 2.6.3. Figure B-28 shows the location of the proposed control structure and diversion channel. A longitudinal cross section through the control structure and transverse cross sections through the diversion channel are shown on Figures B-30 and B-31, respectively. The total first cost of this control structure, diversion channel and appurtenant works, based on July 1979 price levels, is approximately $19.6 million. The corresponding annual cost, after adjustments for finance, operation and maintenance costs, is estimated to be $2.0 million. Table B-5 shows a time profile of all undiscounted and discounted project costs in each year of occurrence over the assumed 50-year economic project life. The present worth of all project costs is approximately $22.5 million.

Table B-5 - Regulation Plan 15S - Project Cost Time Profile

Item	Year	Undiscounted Project Cost[1]	Discounted Project Cost[1]
		$	$
Investment Cost		20,416,000	20,416,000
Operation and Maintenance Cost	1	182,000	167,742
			154,601
			142,489
			131,327
Operation and Maintenance Cost	5	182,000	121,038
			111,556
			102,817
			94,762
			87,338
Operation and Maintenance Cost	10	182,000	80,496
			74,190
			68,378
			63,021
			58,084
Operation and Maintenance Cost	15	182,000	53,533
			49,340
			45,474
			41,912
			38,628
Operation and Maintenance Cost	20	182,000	35,602
			32,813
			30,242
			27,873
			25,690
Operation and Maintenance Cost	25	182,000	23,677
			21,822
			20,113
			18,537
			17,085
Operation and Maintenance Cost	30	182,000	15,746
			14,513
			13,376
			12,328
			11,362
Operation and Maintenance Cost	35	182,000	10,472
			9,652
			8,896
			8,199
			7,556
Operation and Maintenance Cost	40	182,000	6,964
			6,419
			5,916
			5,452
			5,025
Operation and Maintenance Cost	45	182,000	4,632
			4,269
			3,934
			3,626
			3,342
Operation and Maintenance Cost	50	182,000	3,080
Present Worth			22,520,939

1/ Cost estimates are based on July 1979 price levels, 50-year economic project life and an 8-1/2 percent interest rate.

2.7.3 Regulation Plan 6L

Plan 6L addresses a low-range regulation plan that would provide an approximate increase in Lake Erie design outflow of 6,000 cubic feet per second. All five structural alternatives under study could provide low-range increases in lake outflow. Alternatives N3, S1, and S2 were eliminated for economic reasons. Least cost implementation of Plan 6L could be achieved with alternative S3. However, engineering feasibility and future social concerns require selection of alternative L1. The implementation of Plan 6L would best be achieved with a variation of alternative L1 that would restrict the operation of the control gate to a 30-foot open position. This variation would provide an increase in Lake Erie design outflow of 6,800 cubic feet per second. Operational constraints in the Black Rock Canal would reduce the design outflow to a net increase in lake outflow of 3,680 cubic feet per second.

The location of alternative L1 and the regulatory works and remedial measures required to implement Plan 6L are discussed in Section 2.6.5. Figure B-40 shows the location of the proposed control structure. A transverse cross section through the control structure is shown in Figure B-41. The total first cost of this control structure and appurtenant works, based on July 1979 price levels, is approximately $10.3 million. The corresponding annual cost, after adjustments for finance, operation and maintenance costs, is estimated to be $1.2 million. Table B-6 shows a time profile of all undiscounted and discounted project costs in each year of occurrence over the assumed 50-year economic project life. The present worth of all project costs is approximately $13.8 million.

Table B-6 - Regulation Plan 6L - Project Cost Time Profile

Item	Year	Undiscounted Project Cost1/	Discounted Project Cost1/
		$	$
Investment Cost		12,066,000	12,066,000
Operation and Maintenance Cost	1	150,000	138,249
			127,418
			117,436
			108,236
Operation and Maintenance Cost	5	150,000	99,757
			91,942
			84,739
			78,100
			71,982
Operation and Maintenance Cost	10	150,000	66,343
			61,145
			56,355
			51,940
			47,871
Operation and Maintenance Cost	15	150,000	44,121
			40,665
			37,479
			34,543
			31,837
Operation and Maintenance Cost	20	150,000	29,342
			27,044
			24,925
			22,972
			21,173
Operation and Maintenance Cost	25	150,000	19,514
			17,985
			16,576
			15,278
			14,081
Operation and Maintenance Cost	30	150,000	12,978
			11,961
			11,024
			10,160
			9,364
Operation and Maintenance Cost	35	150,000	8,631
			7,955
			7,331
			6,757
			6,228
Operation and Maintenance Cost	40	150,000	5,740
			5,290
			4,876
			4,494
			4,142
Operation and Maintenance Cost	45	150,000	3,817
			3,518
			3,243
			2,989
			2,754
Operation and Maintenance Cost	50	150,000	2,539
Present Worth			13,800,839

1/ Cost estimates are based on July 1979 price levels, 50-year economic project life and an 8-1/2 percent interest rate.

2.8 Impacts on St. Lawrence System

Limited regulation of Lake Erie would involve increasing its outflow during periods of above-average water supply conditions on the upper Great Lakes; i.e., Lake Superior and Lakes Michigan-Huron. It would change the sequence and magnitude of supplies to Lake Ontario. The St. Lawrence Seaway and Power Project was completed in the 1950's in such a way that it would accommodate the highest supply known up to that time (1860-1954). However, record high supplies to Lake Ontario were received in the early 1970's. With the addition of Lake Erie regulation, conditions on Lake Ontario and downstream would be expected to worsen, unless provisions were made to modify the regulation procedure of Lake Ontario and to increase the discharge capacity of the St. Lawrence River.

The types of modifications made to Lake Ontario Regulation Plan 1958-D are described in detail in Section 4.6 of the Main Report and Appendix A, Lake Regulation. Section 3 of this appendix describes the engineering remedial works that would be necessary to accomplish a combined Lakes Erie and Ontario regulation and at the same time meet the IJC existing criteria and other requirements for the regulation of Lake Ontario. It also describes the portion of the remedial works that would be necessary for the regulation of Lake Ontario, with the supplies received through 1976, and to meet the existing IJC criteria.

Section 3

ST. LAWRENCE RIVER SYSTEM

3.1 Preface

The required remedial works in the International and Canadian Reaches of the St. Lawrence River were defined to accommodate a wide range of increased Lake Ontario outflows that would be necessary due to limited regulation of Lake Erie. Following definition of the three regulation schemes and plans under Category 3 as described in Appendix A, preliminary estimates were then made for required remedial works in the St. Lawrence River. It should be noted that the channel remedial works evaluated for the Canadian reach were confined to the Lachine Rapids area near Montreal. While these remedial works would mitigate the flooding problem on Lake St. Louis adjacent to and upstream of Montreal, they would not provide similar relief to riparian interests downstream of Montreal. No remedial works downstream of Montreal were examined, in accordance with the Plan of Study.

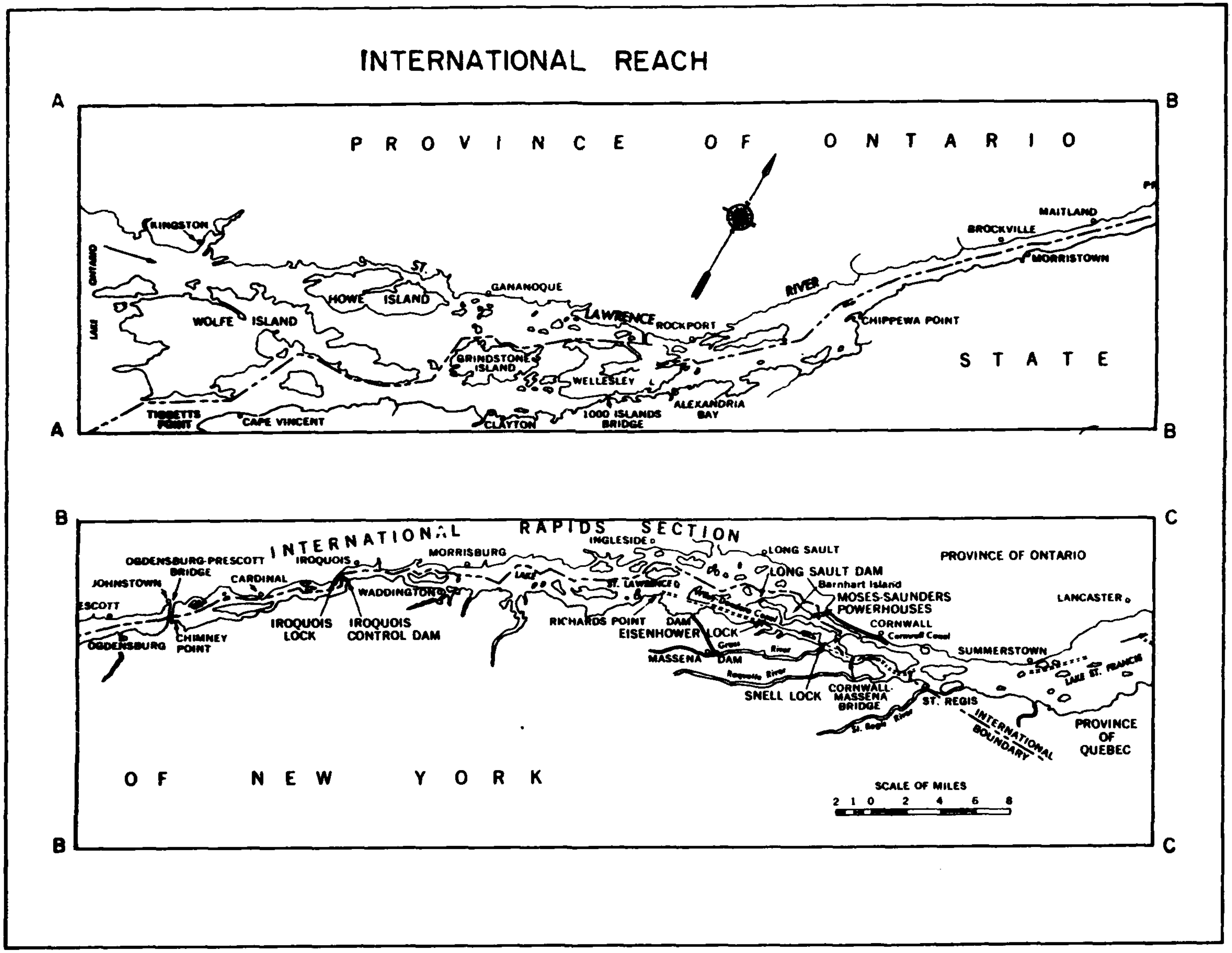
Under Category 3, an adjusted basis-of-comparison was also developed and used in estimating the increasing capacity that would be required in the St. Lawrence River to handle the supplies for the study period 1900-1976 and satisfy the Commission's Orders of Approval for the regulation of Lake Ontario. The required St. Lawrence remedial works for the adjusted basis-of-comparison are also described in this appendix. The differences in capacity increase between those required by the adjusted basis-of-comparison and those required by the Lake Erie plans could be considered the incremental channel enlargements required for combined Lakes Erie and Ontario regulation.

3.2 Description of the Project Area

The St. Lawrence River forms the natural outlet of the Great Lakes drainage basin. From Lake Ontario at Kingston, Ontario, the river flows generally in a northeasterly direction to its outlet on the Gulf of St. Lawrence, at Father Point, Quebec, a distance of some 530 miles. Between Kingston, and Cornwall, Ontario, the river coincides with the International Boundary between Canada and the United States. Downstream of Cornwall, Ontario, the river lies wholly within the Province of Quebec. A location map of the St. Lawrence River is shown on Figure B-44.

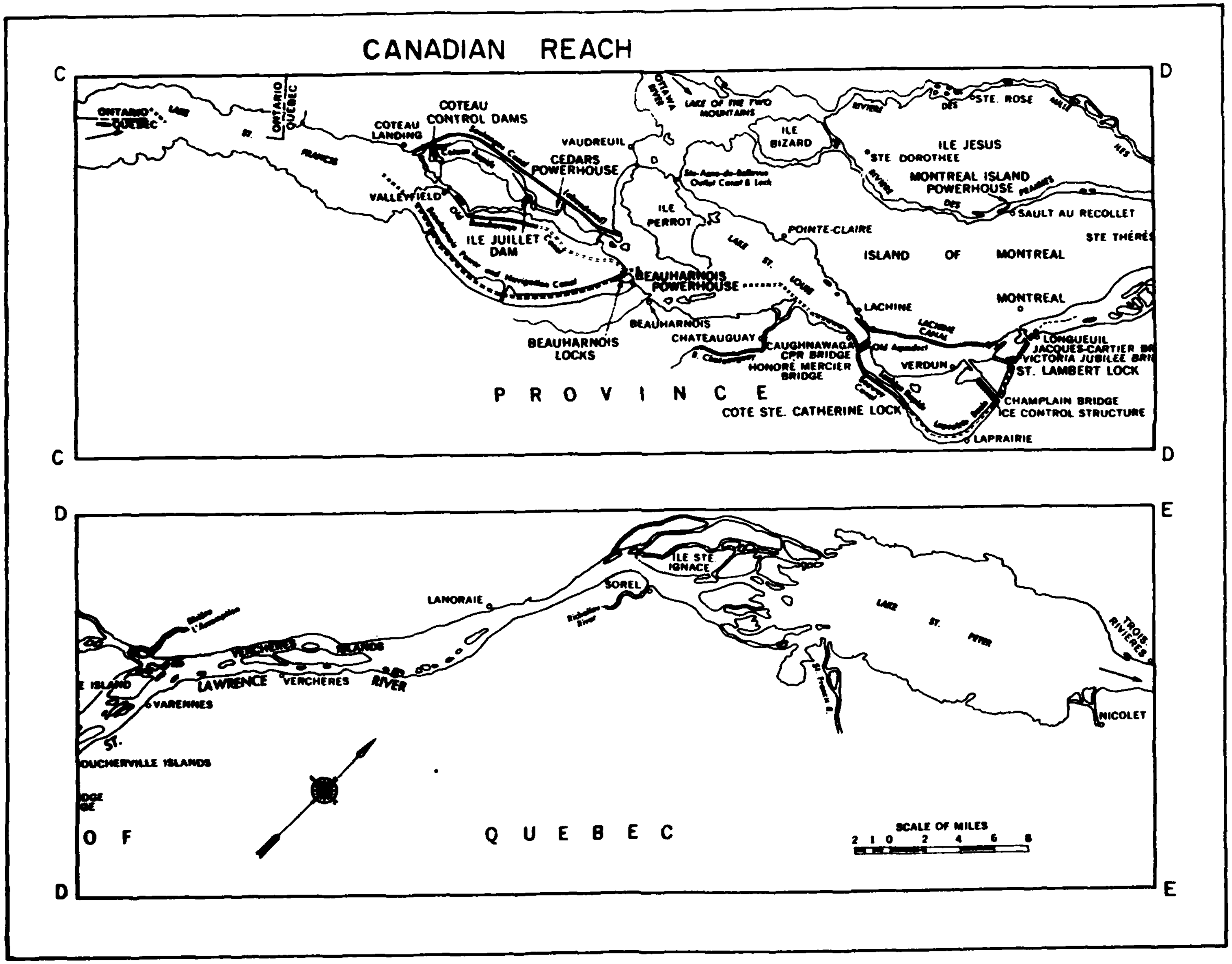
3.2.1 General

The St. Lawrence River possesses some advantages not shared by many rivers of comparable size and importance. The natural regulating effect of the Great Lakes results in a remarkably uniform flow in the St. Lawrence; the ratio of maximum to minimum flow at its headwaters on Lake Ontario being about 2:1 as compared, for example, to the Mississippi River with a corresponding ratio of about 40:1. Over the period 1900-1976, the mean recorded flow was 237,000 cfs, the maximum 350,000 cfs, and the minimum 154,000 cfs.



(Sheet 1 of 2) St. Lawrence River - Location Map

FIGURE B-44



(Sheet 2 of 2) St. Lawrence River - Location Map

FIGURE B-44

From Lake Ontario at Kingston, to Father Point, Quebec, which marks the transition to the Gulf of St. Lawrence, the St. Lawrence River falls approximately 245 feet. Throughout the first 68 miles of its length, the river is characterized by numerous rocky islands and reefs from which the name, Thousand Islands Reach, is derived. With the construction of the St. Lawrence Seaway and Power Project, between 1954 and 1959, the physical features of the next section of the river between Iroquois and Cornwall, Ontario, were considerably changed. The construction of the Saunders-Moses hydro-elecric plants and appurtenances at Cornwall, Ontario - Massena, New York, caused the formation of a large man-made lake, named Lake St. Lawrence, which flooded areas where entire villages had been located. Previous inhabitants of the flooded area were relocated during the Seaway project period.

Below the Saunders-Moses Power Dam, the river divides into two channels around Cornwall Island which then reunite to form Lake St. Francis. Downstream of Lake St. Francis, the river flows through the Beauharnois Canal and Cedars complex to Lake St. Louis. The Beauharnois Powerhouse is located at the end of the canal. At the outlet of Lake St. Louis, the river drops through the Lachine Rapids into the Laprairie Basin and thence through the short, swift flowing section near Victoria Bridge to Montreal Harbour, falling a distance of about 50 feet. Ottawa River waters join the St. Lawrence here at Montreal through the Lake of Two Mountains located to the northeast of Montreal Island, the back rivers to the north of Montreal Island, and the Vaudreuil and Sainte Anne channels connecting Lake St. Louis and Lake of Two Mountains. In the 160 miles of river between Montreal and Quebec City, the fall is about 25 feet at low tide. The range of tide at Quebec City averages about 16 feet, but extreme high spring tides have exceeded 21 feet. The tidal effect diminishes upstream until the maximum range is only about 1-1/2 feet at Trois Rivieres and 1/2 foot at the upper end of Lake St. Peter. Below Quebec City, the river gradually forms its transition into the St. Lawrence estuary and finally the Gulf of St. Lawrence.

International Reach: For the International section of the river extending about 112 miles from Lake Ontario to Cornwall, Ontario-St. Regis, Quebec, the St. Lawrence River is subject to the terms of the Boundary Waters Treaty of 1909 between the two countries. In its first 68 miles to Chimney Point, New York, the river falls about 1 foot. The river varies from 1 to 4 miles in width, is slow moving, and generally deep. The numerous islands and shoals form the Thousand Islands. In the 44 miles from Chimney Point to St. Regis, the river falls approximately 92 feet. Prior to the St. Lawrence Seaway and Power Project, this fall was concentrated in a series of rapids between Chimney Point and Long Sault. However, with the completion of the St. Lawrence Seaway and Power Project, a major portion of the fall occurs at the Saunders-Moses power generation station. Three locks are provided for navigation, one at Iroquois and two in the power development area. Channel excavation was carried out in this section in 1955 in order to meet the criteria in the Order of Approval issued by the International Joint Commission approving construction of the project. The project was designed so that water velocities in the section do not exceed 4 feet per second (fps) during the navigation season or 2.25 fps during the ice formation period in the winter in order to minimize the difficulties of power generation.

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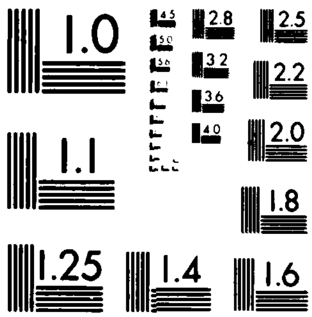


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

Canadian Reach: Downstream from St. Regis, Quebec, the St. Lawrence River lies wholly in Canada and all alterations for navigation downstream to Montreal have been carried out by the St. Lawrence Seaway Authority. Below Cornwall Island, the navigation channel crosses Lake St. Francis for a distance of 31 miles to the head of the Beauharnois Power Canal. The water level of Lake St. Francis is maintained very closely to 152 feet, IGLD (1955) through operation of the Beauharnois Cedars Complex by Hydro-Quebec. In authorizing diversions of water for power purposes at Beauharnois, the Government of Canada passed legislation in 1932 specifying certain conditions which would enable the power canal to be used ultimately as part of the Seaway System. Hydro-Quebec has been required to maintain the canal to give a clear width of 600 feet on the bottom, a depth of 27 feet at low water datum stage, and to provide adequate cross-sectional area so as to produce average velocities not exceeding 2.25 fps under any condition of operation.

Two Seaway locks overcome the 84-foot fall between Lake St. Francis and Lake St. Louis. Downstream of Beauharnois, the river widens into Lake St. Louis which extends for 10 miles to the Lachine Rapids. The navigation channel then bypasses the Lachine Rapids and reaches Montreal through Seaway facilities which consist of two locks: one at Cote Ste. Catherine; the other at St. Lambert.

3.2.2 Existing Regulatory and Power Facilities

The four major installations in the St. Lawrence River between Lake Ontario and Montreal are the Iroquois Dam, Long Sault Dam, Saunders-Moses Plants, and Beauharnois-Cedars complex. In addition, channel enlargements were carried out for the Seaway and power projects.

Iroquois Dam: The Iroquois Dam extends about 1,980 feet from Point Rockway in the United States to the Canadian shore near Iroquois. The structure is equipped with thirty-two 50-foot sluices designed to pass a maximum lake outflow in excess of the maximum flow of 310,000 cfs as specified by the current regulation plan (1958-D). If necessary, the dam can be operated to control and regulate the outflow from Lake Ontario, replacing the natural control provided by a rock ledge which existed near Galop Island prior to alterations associated with the project. The pattern of gate settings for the dam was developed from hydraulic model tests and have been selected so as to minimize adverse currents in the navigation channel at the lower approach to the Iroquois Lock. During periods of strong westerly winds, the gates may be dipped to prevent excessive buildup of water levels in Lake St. Lawrence. The gates are also used during ice formation to assist in promoting a stable ice cover.

Long Sault Dam: Long Sault Dam is located below the foot of Long Sault Island, about 25 miles downstream of the Iroquois Dam. It measures about 2,960 feet along its curved axis. Besides a non-overflow section, it also has a spillway section which consists of thirty 50-foot sluices. The spillway discharge has capacity in excess of requirements at the Saunders-Moses power plants. It also can effectively control the river flows and water levels within specified ranges in the event that flows cannot be discharged through the Saunders-Moses plants.

Saunders-Moses Plants: The Saunders-Moses Plants are located about 3.5 miles downstream from Long Sault Dam and about 2 miles west of Cornwall, Ontario. The 3,300 feet long plant, with a rated head of 81 feet contains thirty-two 57,000 kilowatt capacity generators. Sixteen generators are operated by the Power Authority of the State of New York while the other sixteen are operated by Ontario Hydro. Impounded behind the concrete gravity dam of the power plants is the man-made Lake St. Lawrence, which extends upstream to Iroquois Dam.

Beauharnois and Cedars Complex: At the lower end of Lake St. Francis, about 32 miles east of Cornwall, Ontario, the major part of the St. Lawrence is diverted through a 15-mile navigation and power canal to Hydro-Quebec's generating station at Beauharnois. The Beauharnois Powerhouse has 36 main generating units with a total capacity of 1,574,260 kilowatts at a rated head of 80 feet. The 600-foot wide, 27-foot deep navigation channel occupies the left edge of the 3,500-foot wide Beauharnois Canal. Two locks at the confluence with Lake St. Louis allow ships to transit the 80-foot differential in elevation between Lake St. Louis and the canal.

The remaining portion of St. Lawrence flow leaves Lake St. Francis through the Coteau Control Dam down the natural river channel. Most of this water is utilized by the generating station at Cedars which is also operated by Hydro-Quebec. The Cedars powerhouse has 18 generating units with a total capacity of 162,000 kilowatts at a rated head of 35 feet.

Channel Enlargements: An integral part of the St. Lawrence Seaway Power Project was the channel dredging and excavations carried out to:

1. Provide a channel depth, width, alignment, and water velocity for 27-foot navigation;

2. Reduce velocities to induce winter ice cover over most of the river thus minimizing operational problems and enhancing the channel carrying capacity of the river subsequent to the ice forming period;

3. Distribute the flow in such a way as not to interfere with navigation; and

4. To reduce head losses at specific points, to increase the channel capacity and to maximize the head available for hydro-electric power generation.

For the most part, channel enlargements carried out for power or navigation interests were beneficial to each other.

The International Joint Commission, in its 1952 Orders of Approval, specified that the Power Entities were required to undertake channel enlargements which would ensure that velocities through the Galop section not exceed 4 fps and below Galop down to Morrisburg, not exceed 2.25 fps during the ice forming period. Minimum depths of 29.5 feet upstream of and 28.5 feet downstream of Iroquois were required. The Power Entities carried out channel enlargements in nine principal areas, while the navigation

agencies carried out dredging in three. The principal locations of channel enlargements, carried out by the Power Entities, were at Chimney Point, Galop Island, Lalone-Lotus Islands, Sparrow Hawk Point - Toussaints Island, Iroquois, Point Three Points, Ogden Island, headrace of Long Sault Dam and tailrace of the Saunders-Moses Dam. The principal location of channel enlargements carried out specifically for navigation were at the Iroquois Lock, Wiley-Dondero Ship Channel, and North and South of Cornwall Island.

Approximately 107 million cubic yards of material were excavated during the Seaway Project. The excavations carried out by the Power Entities totaled 63 million cubic yards. The excavations carried out by the navigation agencies totaled 44 million cubic yards.

As an example of the channel capacity increase attained by the project, a flow of 350,000 cfs was discharged out of Lake Ontario during portions of 1973 and 1976. During the latter part of the Summer of 1973, this was about 19,000 cfs in excess of the flow that would have occurred prior to the project. Although, it was physically possible to release a greater flow out of Lake Ontario, it would have had very serious effects on navigation, shorefront properties on Lake St. Lawrence and in the Montreal area, and on the generation of power on the St. Lawrence.

3.2.3 Current Operating Plan

Appendix A, Lake Regulation, discusses details of the current operating plan used in regulating the outflows of Lake Ontario.

3.2.4 Navigation Facilities

Works of the Federal Seaway agencies of Canada and the United States provide a 27-foot navigation channel through the river between Lake Ontario and Montreal Harbour. At and below Montreal, a 35-foot navigation channel is maintained by the Canadian Ministry of Transport.

St. Lawrence Seaway: From Montreal to Lake Ontario, a vessel travels 182 miles and rises over 225 feet. This distance may be considered to consist of five sections, three of which are solely in Canadian waters, the others in International Boundary waters.

The first section, about 31 miles in length, contains the St. Lambert and Cote-Ste-Catherine Locks, which enable ships to bypass the Lachine Rapids and to rise 50 feet above the level of Montreal Harbour. After moving through Lake St. Louis, ships enter the second section, the Soulanges Section, which extends for a distance of 16 miles into Lake St. Francis. The Lower and Upper Beauharnois Locks lift ships a total of 82 feet above Lake St. Louis. The third section, Lake St. Francis, is 29 miles long and terminates just east of Cornwall, Ontario.

The first of the two International Sections of the St. Lawrence Seaway is entered at the upstream end of Lake St. Francis and extends to a point just east of Ogdensburg, New York. It is mainly the man-made Lake St. Lawrence resulting from the construction of the Saunders-Moses power complex.

The major difference in elevation is overcome by the United States Snell and Eisenhower Locks near Massena. The Iroquois Lock, located beside the Iroquois Dam on the Canadian side, bypasses the Iroquois Dam and is operated by the St. Lawrence Seaway Authority in Canada. The remaining section, known as the Thousand Island Section, extends from here over 68 miles into Lake Ontario.

3.2.5 Bridges, Wharves, Ferries, and Other Facilities

There are 15 bridges spanning the St. Lawrence River, all of which provide a vertical clearance of at least 120 feet above high water to accommodate commercial vessels. The Louis Hippolyte Lafontaine tunnel carries vehicular traffic under the St. Lawrence River at the head of Boucherville Islands, downstream of Montreal. Other tunnels carry vehicular traffic under the Lower Beauharnois Lock at Melocheville, Quebec, and the Eisenhower Lock near Massena, New York.

Two commercial wharves with a depth of 27 feet below low water datum are located in Montreal, namely Port de Valleyfield and Lower Lakes Terminal. There are 46 wharves with a maintained depth of less than 27 feet, of which 44 are located in Canada and two in the United States.

There are a total of 11 ferry routes on the St. Lawrence. Below Quebec City, ferries traverse the river between: Quebec City and Levis; Riviere-Du Loup and St. Simeon; Trois Pistoles and Les Escoumins; Rimouski and Baie Comeau; Matane and Godbout; and Ste. Anne-des-Monts and Sept-Iles. Above Quebec City, there are ferry crossings between: Sorel and Berthierville; the city of Dorval and Ile Dorval; Kingston and Wolfe Island with stops at Simcoe and Garden Islands; Simcoe Island and Wolfe Island; and Wolfe Island and Cape Vincent, New York. In addition, there are several scenic boat tours in operation during the tourist season throughout the river system.

There are sixteen submarine cables and four major overhead transmission lines across the St. Lawrence River.

3.3 Selection of Remedial Works Alternatives

3.3.1 International Reach

Based upon the water supplies for the study period 1900-1976, the existing channels of the St. Lawrence River were found to have inadequate capacity to convey the additional outflow from Lake Ontario that would result from the limited regulation of Lake Erie. In order to meet the regulation criteria and other requirements in the existing Orders of Approval of the International Joint Commission for the regulation of Lake Ontario, remedial works would therefore be necessary in the International Reach of the St. Lawrence River. These remedial works would take the form of channel enlargements in certain restricted segments of the International Reach. The existing regulatory and power facilities, as described in Section 3.2.2, would provide adequate flow retardation and water level control in this reach subsequent to these channel enlargement measures. To provide a range of

increased hydraulic conveyance capacities in this reach of the St. Lawrence along with associated costs to permit regulation plan development under Category 3 evaluations, five channel enlargement schemes were developed (Section 3.5.2). These schemes permit increased outflows from Lake Ontario of up to 30,000 cfs. After reviewing these schemes, it became apparent that excavation along side the navigation channels was the most efficient and cost effective way to achieve the required conveyance capacities, particularly at restricted locations such as Chimney Point - Galop Island area.

In order to better define the locations and amounts of channel excavations, physical modelling would be required. Such model studies would provide more detailed information on the effects of channel excavation on the flow velocities and water surface profile.

3.3.2 Canadian Reach

Channel enlargement at Lachine Rapids would be required to mitigate flooding of lands adjacent to Lake St. Louis. Depending on the amount of channel enlargement, a compensating structure at Lachine might also be necessary to offset the effect of channel enlargement at lower flows. To provide a range of increased channel capacities at the Lachine section and associated costs, several schemes were developed permitting increased outflows from Lake St. Louis of up to 50,000 cfs. As previously noted, the possibilities of remedial works downstream of Montreal were not examined in this study. If limited regulation of Lake Erie were to proceed, such remedial works would most likely be required to mitigate flood problems downstream of Montreal.

3.4 Hydraulic Considerations

The principal hydraulic considerations utilized in studies of the St. Lawrence River remedial works are discussed below.

3.4.1 Assumptions

In determining the requirements for combined Lakes Erie and Ontario regulation, the following assumptions and limitations were used:

1. The remedial works, in terms of channel excavations, would provide sufficient capacity during the 50-year life of the project;

2. The remaining life of existing regulatory and power facilities, with proper maintenance, would be about 50 years;

3. The general flow and current pattern in the river would be maintained;

4. The existing ice regime would be maintained in the system and the ice booms would be kept in operation;

5. The control structure at Lachine would be operable all year; and

6. The outflow of Lake Ontario would be regulated in accordance with Plan 1958-D, modified to the extent necessary which would depend on the amounts of channel enlargements. Recent studies by the International St. Lawrence River Board of Control have confirmed that it is not practical within existing physical constraints to design a Lake Ontario regulation plan which would meet all IJC criteria and other requirements under the maximum supply received to date. The St. Lawrence River Board has recommended that Plan 1958-D, with discretionary actions such as those used in the past, be continued as the plan of regulation of Lake Ontario.

3.4.2 Ice Problems

Ice problems in the St. Lawrence can in general be related to the restrictive effects of the ice on river discharge, the magnitude of which varies from reach to reach depending on the configuration and hydraulic conditions of the river. For example, the formation of ice jams upstream of a generating station can seriously reduce the flow to the turbines, resulting in a loss of generated power, while at the same time causing flooding above the jam. Therefore, to overcome these problems the formation of a stable and relatively smooth ice cover early in winter is an important factor. The use of floating ice booms is a proven method of establishing stable ice cover. Below Montreal, the problem is somewhat different in that the aim is to maintain an open channel for navigation and flood prevention. One of the attendant difficulties is to keep flushing the ice downstream through areas where flow velocities are low.

At the present time, the only measures taken to control ice in the St. Lawrence between Lake Ontario and Montreal relate to the requirements of hydroelectric power development at the Saunders-Moses plants and the Beauharnois-Cedars complex. In the International Reach, the first booms were placed at the beginning of the 1959-1960 winter period and an additional boom was installed a year later. The overall layout of the booms has remained unchanged since the winter of 1961-1962 and consists of a boom across the river at Ogdensburg-Prescott, a short section at Chimney Point, and four booms in the Galop Reach. Ice booms are at present utilized in two areas in the Canadian Reach. Booms are placed each winter in the Beauharnois Canal by Hydro-Quebec, and in the St. Lawrence River downstream of Montreal by the Ministry of Transport. Artificial islands to stabilize ice cover have been recently placed in Lake St. Louis to mitigate ice jam problems. Downstream of Montreal, where the emphasis is on maintaining an open channel for flood control and navigation, systematic icebreaking operations provide the main control. Some experimental work with ice booms is also being conducted.

3.4.3 Methodology

International Reach: In order to estimate the channel enlargements required to discharge a wide range of Lake Ontario outflows, an unsteady-state mathematical model was used for the upper St. Lawrence River from Lake Ontario to Cornwall-Massena. Figure B-44 shows the location of this area.

The model computes the water surface profile, velocities, etc., resulting from various assumed extents of channel enlargements. The model, designed and calibrated by the Great Lakes Environmental Research Laboratories of the National Oceanic and Atmospheric Administration (NOAA), is capable of simulation on varying time increments and includes flow under ice-covered, as well as open-water, conditions.

The objective in developing this mathematical model was to evaluate water surface changes due to channel dredging, changing ice covers, and the effect of extending the navigation season on the St. Lawrence River. In this study, the model was used to estimate the nature and extent of channel excavation required to meet the hydraulic requirements of any given combined Lakes Erie and Ontario regulation plan. For any given excavation alternative, the model was used to determine the resulting water surface elevations and average channel velocities at strategic locations along the river.

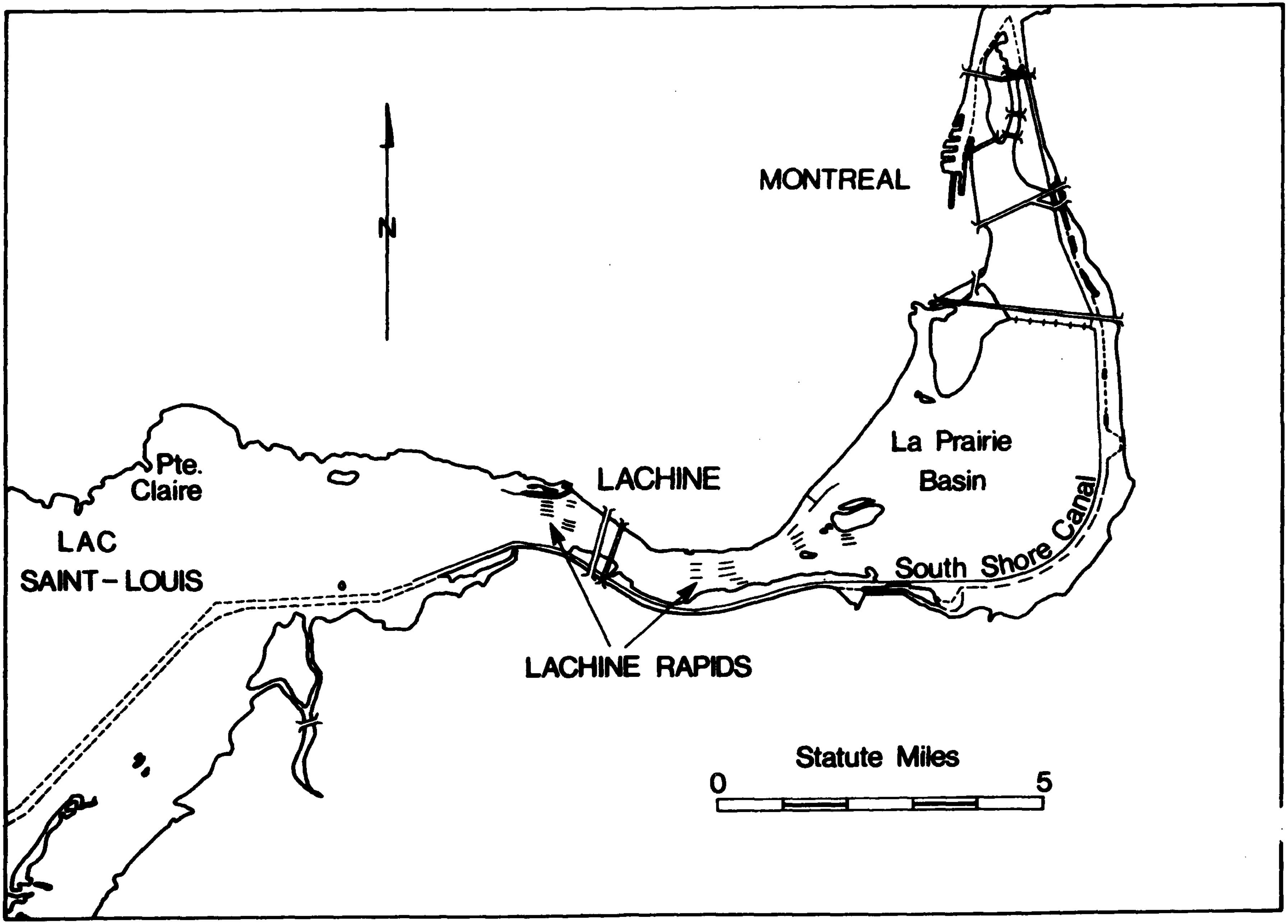
The section of the St. Lawrence River simulated by the NOAA model extends from Lake Ontario to the Moses-Saunders Power Dam near Cornwall, Ontario-Massena, New York. A detailed description of the model, its development and calibration, etc., are contained in NOAA's Technical Memorandum ERL GLERL-24 Upper St. Lawrence River Hydraulic Transient Model, October 1978. The following is a brief description of the model.

The configuration in the model consists of 30 reaches interrelated by 21 intersection or nodal points. Each reach is assumed prismatic with its own physical characteristics of length, width, wetted area, wetted perimeter, and bed roughness. Input to the model consists of the initial stage and flow conditions along the river, the respective channel roughness coefficients, ice-cover roughness coefficients, and ice thickness for all the reaches. A net total supply (NTS) hydrograph or water level hydrograph is allowable input as upstream boundary conditions. Downstream boundary conditions include a discharge or water level hydrograph at the powerhouse.

Because plans of regulation were selected subsequent to study commencement, a range of channel excavations which would likely encompass those of the selected Lakes Erie and Ontario regulation plans was simulated. Section 3.5.2, *Channel Enlargements*, describes in detail how the amounts to be excavated were estimated.

Canadian Reach: For Lake Erie regulation plans designed to increase discharges which in turn would permit increased Lake Ontario outflows, channel enlargement at Lachine Rapids would be required to mitigate flooding of lands adjacent to Lake St. Louis. A compensating structure at Lachine might also be necessary to offset the effect of channel enlargement during periods of lower flows. Figure B-45 shows the location of the Lachine Rapids area.

Because plans of regulation were initially not available, alterations for a range of Lake St. Louis level and outflow conditions had to be considered. Section 3.5.3, *Channel Enlargements*, describes in detail how the amounts of excavation required for regulation plans were estimated.



Lachine Rapids Area of the St. Lawrence River - Location Map

FIGURE B-45

The analysis consists of determining the additional channel area of the river needed to carry the increased discharge at the same level of Lake St. Louis as for an outflow of 390,000 cfs. This flow is considered as the base flow and corresponds to an elevation 72.2 feet, IGLD (1955), or 72.5 feet, G.S.C. at Point Claire Gauge. Flood damage begins when this level is exceeded. The procedure was essentially trial and error using the HEC-2 backwater analysis from the bottom of Lachine Rapids to Lake St. Louis with different dredging dimensions at certain locations until the particular level condition was satisfied. Much information with respect to optimum areas for dredging was available from earlier Canada-Quebec flood studies of the Montreal area. Also from the Canada-Quebec study, it was determined that the most effective way to maintain low lake levels in their present range was by isolating the upstream dredged area by an in-river dike and control structure at the head of the dredged channel. This would enable all the flow to be passed down the remaining river channel when necessary. The hydraulic analysis for this low level condition consists of assessing the length of dike which would cause the low level on the lake to be restored to natural, thus negating the effect of the increased river area by dredging. It remained also to verify high water conditions once the dike length was determined by apportioning flows through the dredged and river channel, and checking the lake levels.

3.5 Design and Cost Estimates

Common design criteria were used throughout the design process in order that a valid comparison of cost could be made between the various remedial alternatives under study. All depths and heights given are in feet; all elevations are referred to the International Great Lakes Datum (1955).

3.5.1 Topographic and Geotechnical Characteristics

Channel excavation in the International Reach of the St. Lawrence River would extend from Ogdensburg, New York to Morrisburg, Ontario, a distance of about 20 miles. While the amount of channel enlargement varies depending on the required increase in channel capacity, the locations of dredging are generally the same. Information on dredged material is based on borings taken in the 1950's by Ontario Hydro, U. S. Army Corps of Engineers, and the Power Authority of the State of New York in connection with the development of the Seaway and Power Project. The material to be excavated is glacial till overburden consisting of mostly fine and coarse sand, grey clay, boulders, and gravel. The underlying bedrock is classified as Beekmantown Dolomite.

Channel excavation in the Canadian Reach of the St. Lawrence River is limited to the Lachine Rapids area. The material to be excavated is believed to be limestone and, for the purposes of cost estimates, all excavation was assumed into rock. For more detailed design information, extensive test borings would be necessary.

3.5.2 International Reach

Hydraulic Design: As stated in Section 3.2.1, the channel modifications made in the river during the Seaway and Power Project development were designed to provide velocities in the navigation channel not exceeding 4 feet per second (fps) during the navigation season or 2.25 fps during the ice formation period. It should be noted, however, that these channel design velocities are currently exceeded in some areas of the shipping channel under existing flow conditions. Therefore, any channel enlargements to accommodate limited Lake Erie regulation should not produce higher flow velocities than those which presently occur. In other words, the resulting average velocity in any cross section of the navigation channel should not be increased. Based on this rationale, channel excavation quantities, adjacent to the navigation channel, were computed to handle the additional discharges at 4 fps. Although these velocities are not expected adjacent to the shore or channel banks, they would induce the required capacity in adjacent portions of the river cross sections. Under various defined channel enlargements, the NOAA mathematical model was used to compute the resulting water surface profiles and channel velocities. Sufficient computations, using a wide range of Lake Ontario outflows, were performed to define the modified outflow limitation curves.

To present a range of hydraulic conditions that might result from combined Lakes Erie and Ontario regulation, five channel excavation alternatives in the International Reach of the St. Lawrence were examined. These alternatives are described in Table B-7.

Table B-7 - Excavation Alternatives in the International Reach of the St. Lawrence River

Excavation Alternative	Description of Excavation Alternative	Total Estimated Excavation Volume (millions of cubic yards)
1	Excavation from Chimney Point to Morrisburg, adjacent to the navigation channel and to permit a flow increase of 10,000 cfs at Lake Ontario elevations above 244.5 feet IGLD (1955)	7.5
2	Excavation from Chimney Point to Morrisburg, adjacent to the navigation channel, and to permit a flow increase of 20,000 cfs at Lake Ontario elevations above 244.5 feet IGLD (1955)	15.0
3	Excavation from Chimney Point to Morrisburg, adjacent to the navigation channel, and to permit a flow increase of 30,000 cfs at Lake Ontario elevations above 244.5 feet, IGLD (1955)	22.2
4	Excavation and hydraulic capacity as per alternative 2 but with channel excavation in the Galop and Ogden Island areas located in the channels on the south side of these islands rather than adjacent to the north side navigation channels.	20.0
5	Excavation similar to alternative 2 but limited to the Iroquois Dam to Morrisburg reach adjacent to the navigation channel. This will permit flow increases up to 20,000 cfs at Lake Ontario elevations above 245.7 feet IGLD (1955)	4.9

The fourth alternative mentioned above was considered since it was expected that interference with navigation could be reduced, although it would require more channel enlargement when compared to the second alternative. The fifth alternative assumes that the additional channel capacity would be required at a higher Lake Ontario elevation.

Figure B-46 shows the relationship between the amounts of channel excavation and river flow increases. The effect of the above five excavation alternatives on maximum Lake Ontario outflow limitations are as depicted in Figure B-47. The locations of the channel enlargement are shown in Figure B-48. Each of the five excavation alternatives is expected to have no effect on the existing minimum draft conditions in the Seaway. It is recognized that operation of the Iroquois Dam will be required on a more frequent basis than is currently the case, as these channel modifications would otherwise cause increased Lake St. Lawrence levels.

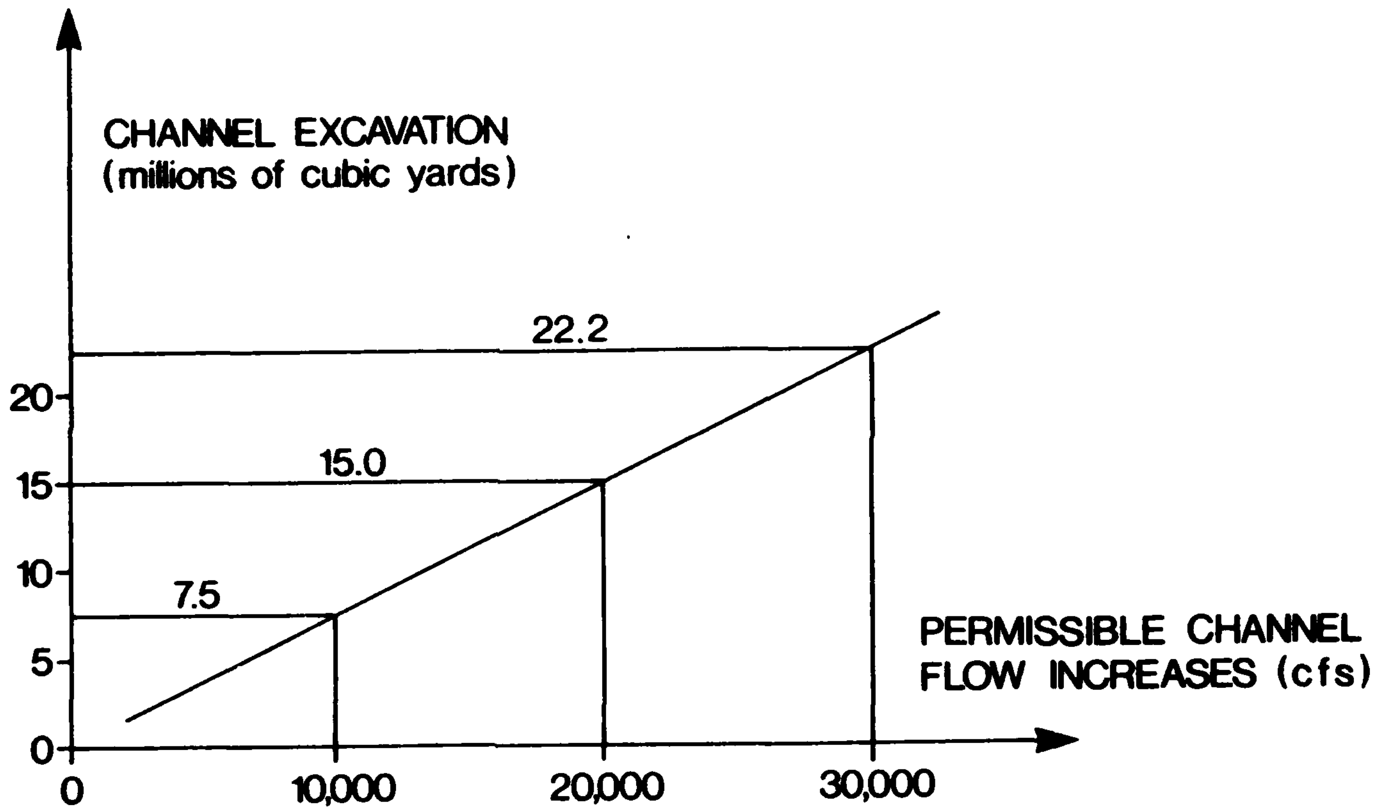
The excavation alternatives listed above would have varying effects on the existing head-loss relationship for the river from Lake Ontario to the Saunders-Moses Powerhouse. In order to define more accurately the hydraulic effect and costs of these excavation alternatives, it would be necessary to employ more sophisticated and elaborate mathematical and hydraulic model studies of this reach of the river.

Channel Enlargements: As indicated in the preceding section, *Hydraulic Design*, five excavation alternatives, providing various capacity increases, were examined. This section describes the procedure in determining the required channel excavation to accommodate Lakes Erie and Ontario regulation. It also describes the procedure in determining the required channel excavation required by the adjusted basis-of-comparison.

Since the completion of the St. Lawrence Seaway and Power Project in 1959, the outflow of Lake Ontario has been completely regulated. All channel enlargements, as approved by the Governments of Canada and the United States in 1955, were designed to give a maximum mean velocity in any cross section of the navigation channel not exceeding 4 feet per second during the navigation season and 2.25 feet per second during the ice formation period in the winter to minimize the difficulties of power generation. Plan of Regulation 12-A-9 was specified in the IJC Order of Approval to be used as a basis for calculating critical profiles and designing channel excavations. All excavations were designed to cope with the highest-known supply conditions during the period 1860-1954.

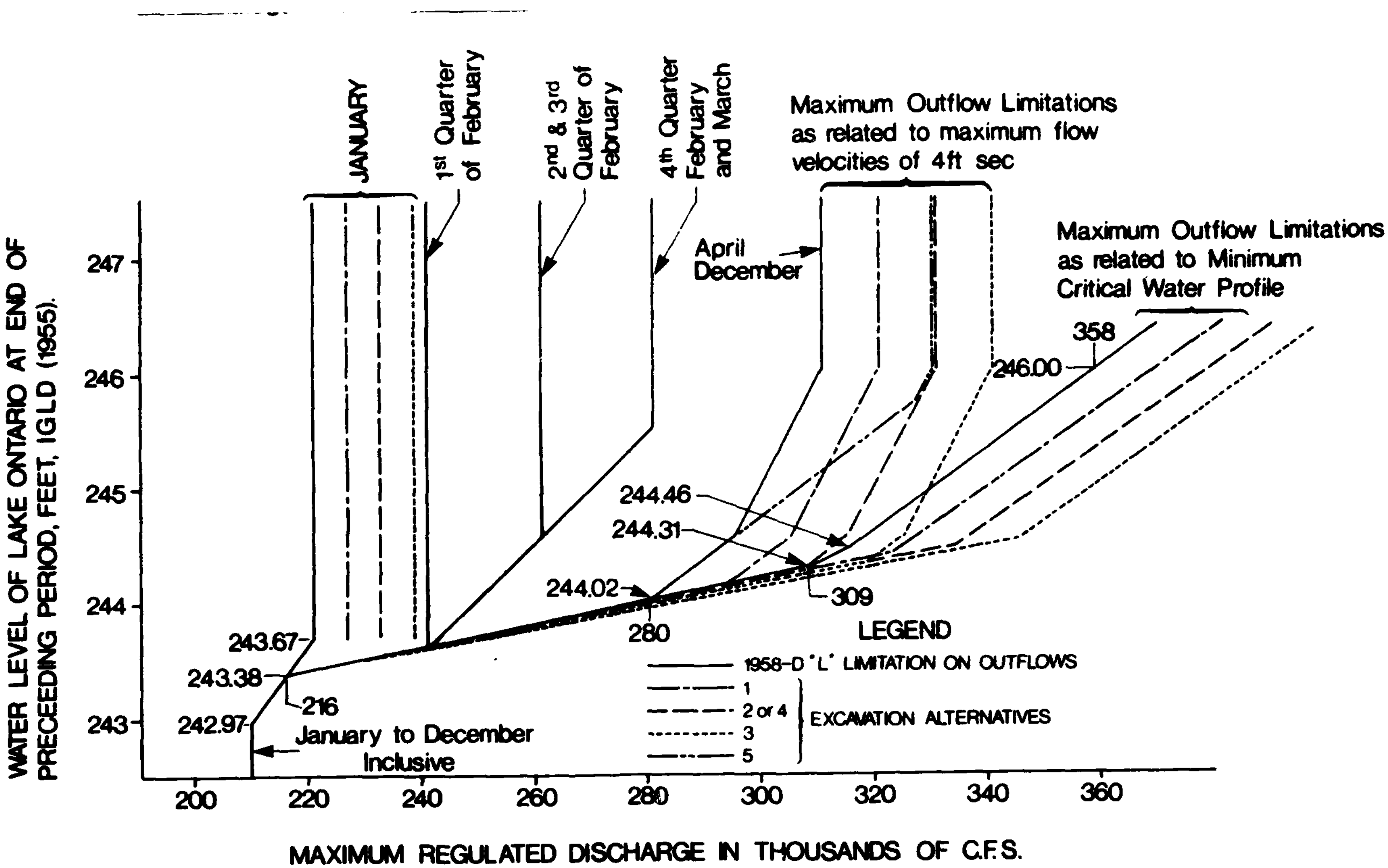
The present regulation plan used to regulate Lake Ontario outflow is Plan 1958-D. It was designed in 1963 to satisfy the IJC criteria and other requirements that have been established to protect or to provide benefits to the various interests concerned. Similar to Plan 12-A-9, Plan 1958-D was also tested over the period 1860-1954 to assess the degree to which it satisfied the IJC criteria and other requirements.

Limited regulation of Lake Erie would alter the sequence and the magnitude of supplies to Lake Ontario. Since the regulated Lake Erie outflow would be higher than that under the basis-of-comparison during high supply



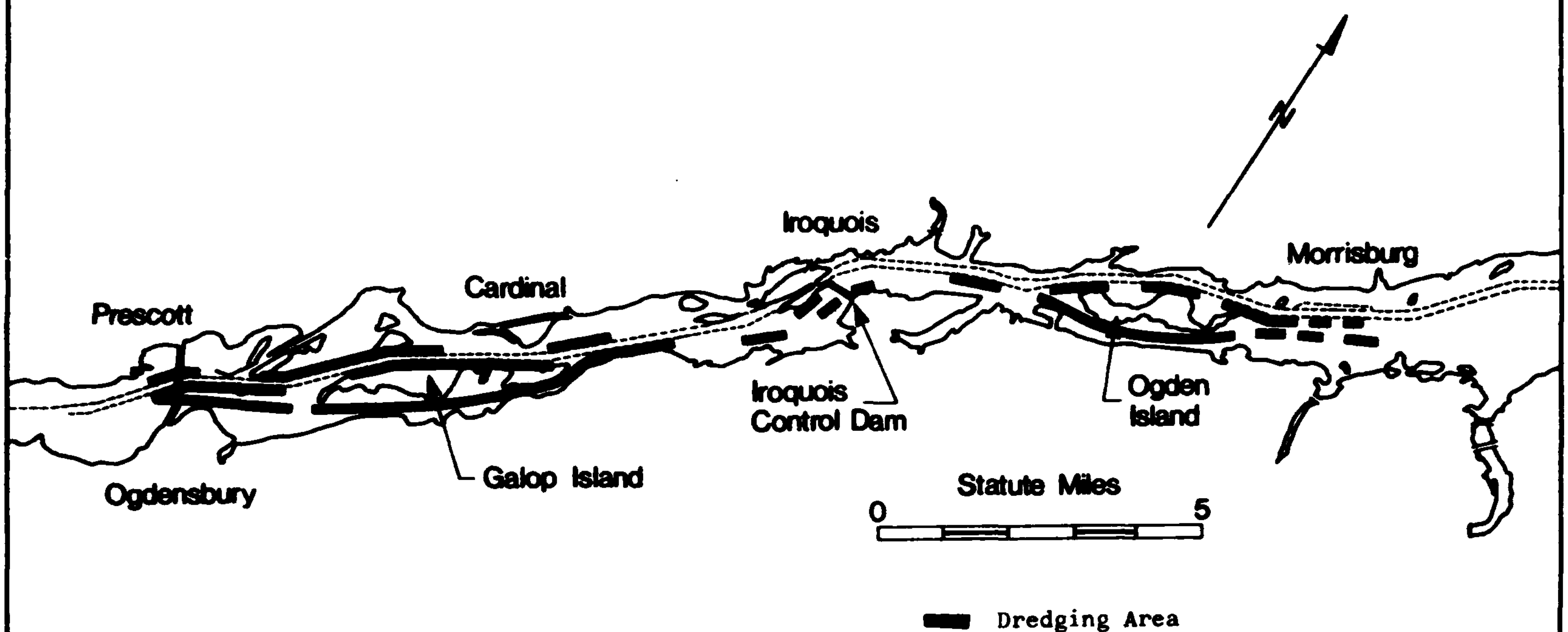
Amount of Excavation in the International Reach of the St. Lawrence River vs. Permissible Flow Increases

FIGURE B-46



MAXIMUM LAKE ONTARIO OUTFLOW LIMITATIONS
For Existing Channel Conditions and Potential St. Lawrence River Excavation Alternatives.

FIGURE B-47



Note: Channel Excavation on the south side of Galop and Ogden Islands would be required under Alternative 4 (see Section 3.5.2, Hydraulic Design)

Location Map of Channel Enlargement in the International Reach of the St. Lawrence River

FIGURE B-48

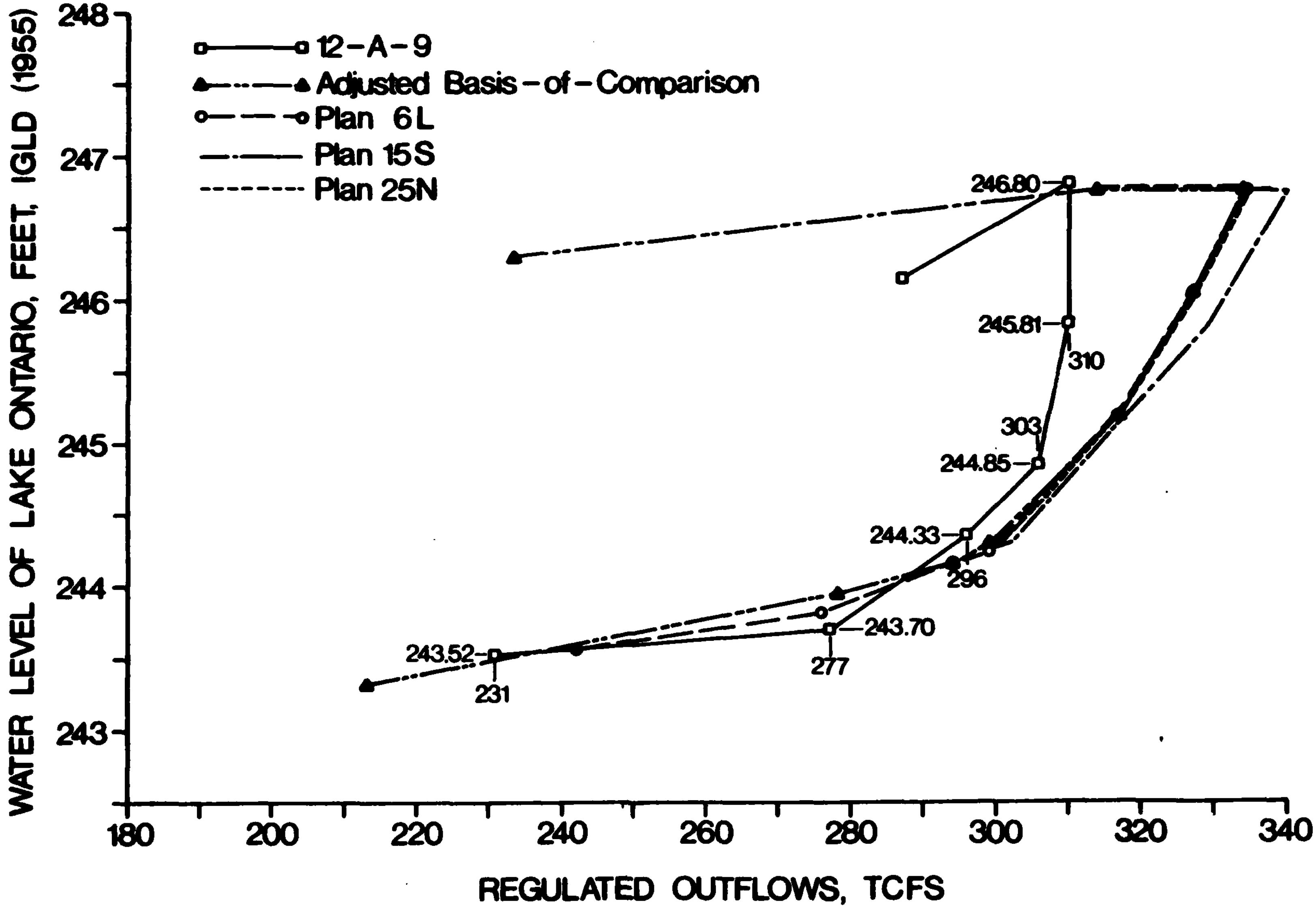
periods, Lake Ontario levels would increase unless provisions were made to discharge the additional water down the St. Lawrence River. To maintain existing water level profiles under increased Lake Ontario outflow conditions and not exceed existing maximum flow velocities in the navigation channels, dredging would be required in certain reaches of the river. It should be noted that channel design velocities are currently exceeded in some areas of the shipping channel under existing flow conditions. During the high supply period of the early 1970's, the maximum velocity requirement was often exceeded for sustained periods of time in order to discharge outflows higher than the channel was designed for. For the purpose of this study, it was considered that any limited Lake Erie regulation should not produce more critical conditions on the St. Lawrence River than those of Plan 12-A-9.

The adjusted basis-of-comparison was developed under Category 3 in order to define channel excavations that would be necessary to accommodate the recorded supplies for the study period 1900-1976 and satisfy the IJC's criteria for the regulation of Lake Ontario. Plan 1958-D would be modified to take advantage of such excavations. Furthermore, Plans 6L, 15S, and 25N under Category 3 were developed to define the channel excavations that would be necessary to accommodate the combined Lakes Erie and Ontario regulation. Plan 1958-D would also be modified. The differences between the two quantities of excavation would represent the incremental excavations required solely for limited regulation of Lake Erie. The development of Category 3 adjusted basis-of-comparison and Lakes Erie and Ontario regulation plans is described in Appendix A, Lake Regulation, and Section 4.6 of the Main Report.

Figure B-49 shows the Lake Ontario envelope curves for the open water condition under the three Lake Erie regulation plans; Plans 6L, 15S, and 25N as well as the adjusted basis-of-comparison. These envelopes are based on monthly Lake Ontario water levels versus outflows. Also plotted on this figure is the envelope curve for Plan 12-A-9.

Plan 12-A-9 shows that the critical point occurs at a Lake Ontario stage of 244.33 feet and an outflow of 296,000 cfs. Based on past experience, power operation difficulties would be encountered at a Lake Ontario elevation of about 244.33-244.35 feet. Figure B-49 shows that at this elevation, the adjusted basis-of-comparison as well as Plan 6L would both require an additional capacity, over that of Plan 12-A-9 of about 4,000 cfs. Plan 15S would require an additional capacity of about 6,000 cfs, or an additional 2,000 cfs over that for the adjusted basis-of-comparison or Plan 6L. Plan 25N would require an additional capacity of about 5,000 cfs or an additional 1,000 cfs over that for the adjusted basis-of-comparison or Plan 6L. Figure B-48 shows the locations where channel excavation would be necessary.

It should be noted that detailed engineering studies would be necessary to determine whether or not elevation 244.33 feet would still be the critical level. Preliminary estimates have indicated that higher Lake Ontario outflows at higher Lake Ontario stages would not cause any worse condition to the existing river profile. If a higher Lake Ontario stage, and hence outflow become more critical, then higher capacities would be required. It should also be noted that the envelopes have all been prepared using monthly



LAKE ONTARIO ENVELOPE CURVES FOR THE OPEN WATER CONDITION UNDER THE ADJUSTED BASIS-OF-COMPARISON AND PLANS 6L, 15S, AND 25N

FIGURE B-49

values. This procedure has excluded the quarter-monthly values which, if used, would call for higher capacity increases.

Shore Protection Works: Since channel excavations would be mostly confined to the shallow shoal areas, shore protection was considered not necessary except for the areas at Galop and Ogden Islands. No estimates have been made in this study for such shore protection works.

Cost Estimates: Construction effort relates mostly to dredging in the river. The material to be dredged is assumed to be mostly glacial till, consisting of sand, gravel, and boulders. As discussed in the section above, *Channel Enlargements*, the additional channel capacity required in the International Reach of the St. Lawrence River is 4,000 cfs for the adjusted basis-of-comparison and Plan 6L; 6,000 cfs for Plan 15S and 5,000 cfs for Plan 25N. These would require excavation of about 3, 3.8, and 4.5 million cubic yards, respectively (Figure B-46).

Cost estimates for the remedial alternatives were based on unit costs expected on similar dredging projects in that part of the St. Lawrence River expressed on July 1979 price levels. This includes the transportation and disposal on land of the dredged material. It was assumed that dry land disposal areas would be available. These costs were escalated by a 25 percent contingency allowance to obtain the total direct costs. Indirect costs, which include allowance for detailed investigations, foundation and geological exploration, engineering designs, construction supervision and administration, were estimated at 15 percent of the total direct costs and added to obtain the total estimated first cost. To this was added interest during construction calculated by applying interest at 8-1/2 percent for one-half the estimated construction period to obtain the total investment cost. For the adjusted basis-of-comparison and Lake Erie Plans 6L, 15S, and 25N, excavation in the International Reach of the St. Lawrence River would require about 2 years.

Annual cost as considered here includes all annual costs occurring after activation of a project and is the sum of the finance costs and operation and maintenance costs.

The method used to estimate each of these factors is described below:

1. Finance costs were calculated on an economic project life of 50 years and include interest and amortization. The annual payments provide for payment of interest and a sinking fund to retire the debt in the timeframe of 50 years. An interest rate of 8-1/2 percent was used.

2. Operation and maintenance costs were estimated by applying percentage factors to the direct cost of the items. Because of minimum maintenance expected in the excavated channel, the applicable factor on this expense was 0.26 percent. This cost includes the cost of administration and general expense.

Present worth for each of the excavation alternatives was also calculated based on a 50-year economic project life and the investment cost

discussed earlier. The present worth of the annual operation and maintenance costs was added to the investment cost to determine the total present worth of each alternative. Table B-8 shows the cost estimates of the required remedial measures in the International Reach of the St. Lawrence River.

3.5.3 Canadian Reach

Hydraulic Design: To present a range of channel enlargements at Lachine Rapids that would be required to mitigate flooding in Lake St. Louis, four remedial alternatives in the Canadian Reach of the St. Lawrence were examined. A compensating structure at Lachine was also considered to offset the effect of channel enlargement at low flows.

For the hydraulic analyses required to establish construction estimates, the following criteria were used:

1. The flooding level on Lake St. Louis was taken as elevation 72.2 feet, IGLD (1955) at Pointe Claire gauge. This corresponds to an outflow from Lake St. Louis of 390,000 cfs and, from the best information available, is the level at which flood damage begins. This then is considered the base flow.

2. Analysis and cost estimate for flow increases of up to 50,000 cfs (above 390,000 cfs) were made to provide data for a cost versus capacity increase curve.

3. A low flow value of 220,000 cfs was used for low flow conditions in the evaluation.

Table B-8 - St. Lawrence River Area Remedial Works - Summary of Discharge Capacities and Cost Estimates for Selected Lake Erie Regulation Plans

Alternatives	Increase in Discharge Capacities (cfs)	Cost Estimates 1/ (millions of dollars) First Cost	Average Annual Costs	Present Worth
International				
Plan 6L	4,000	30.0	2.9	33.6
Plan 15S	6,000	45.0	4.3	50.2
Plan 25N	5,000	38.0	3.4	39.1
Adjusted Basis-of-Comparison	4,000	30.0	2.9	33.6
Canadian				
Plans 6L, 15S, and 25N and Adjusted Basis-of Comparison	15,000	41.9	4.0	46.5
Total (International & Canadian)				
Plan 6L		71.9	6.9	80.1
Plan 15S		86.9	8.3	96.7
Plan 25N		79.9	7.4	85.6
Adjusted Basis-of-Comparison		71.9	6.9	80.1

1/ Cost estimates are based on July 1979 price levels, a 50-year economic life, and an 8-1/2 percent interest rate.

Details of the analysis for the discharges considered are as follows:

1. Alternative 1. Flow increase of 50,000 cfs for a total of 440,000 cfs.

2. Alternative 2. Flow increase of 35,000 cfs for a total of 425,000 cfs.

3. Alternative 3. Flow increase of 20,000 cfs for a total of 410,000 cfs.

4. Alternative 4. Flow increase of 15,000 cfs for a total of 405,000 cfs.

It was considered that no control structure would be necessary for the maintenance of lake levels at low flow under Alternatives 3 and 4 above as the lowering would be very small.

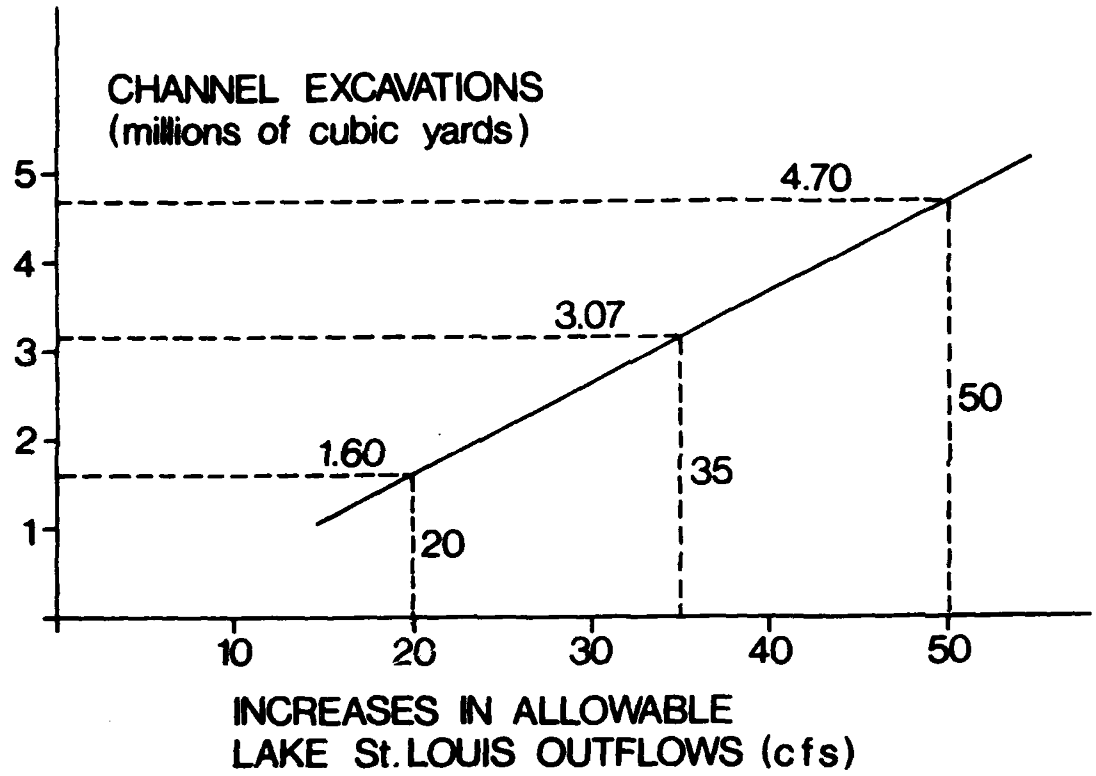
The amount of channel capacities versus excavation quantities are plotted in Figure B-50. The location of the excavation for each alternative is shown in Figure B-51.

Channel Enlargements: One of the requirements for Lake Ontario regulation is that the downstream riparian interests should not experience any worse condition under regulation. Thus, the maximum Lake Ontario outflow limitation, termed P-Limitation, was incorporated into Plan 1958-D to control the deviation of the regulation outflows from those outflows which would occur under pre-project (without Lake Ontario regulation) conditions. Under Category 3 study, it was noted that increasing the P-Limitation by 15,000 cfs in all three selected Lake Erie regulation plans would satisfy the IJC requirements for the regulation of Lake Ontario. The amount of excavation required corresponding to this increase in channel capacity would be about 1 million cubic yards. All removed material was assumed to be sedimentary rock. No control structure was considered necessary to offset the lowering effect during low supply conditions.

Shore Protection Works: Since channel excavation would be confined to the shallow rapids area, shore protection was considered not necessary.

Cost Estimates: The major part of the construction effort relates to dredging of sedimentary rock. Unit costs of concrete, earthfill, excavation, etc., affecting the control structure costs have been based in part, on figures used for previous Montreal flood studies. They have been updated according to a Canadian ENR index from December 1974 to December 1977 by a conversion factor of 1.45. They were further updated to July 1979 by a conversion factor of 1.20.

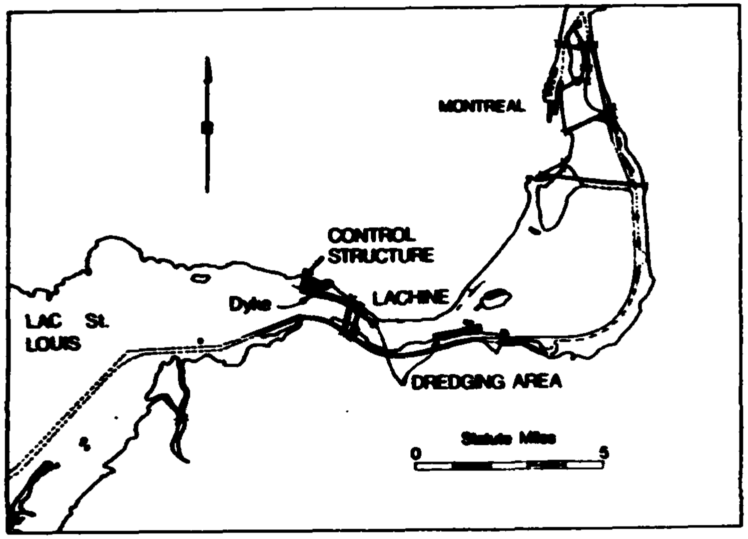
The costs computed were escalated by a 25 percent contingency allowance to obtain the total direct costs. Indirect costs, which include allowance for detailed investigations, foundation and geological exploration, engineering designs, construction supervision and administration, were estimated at 15 percent of the total direct costs and added to obtain the



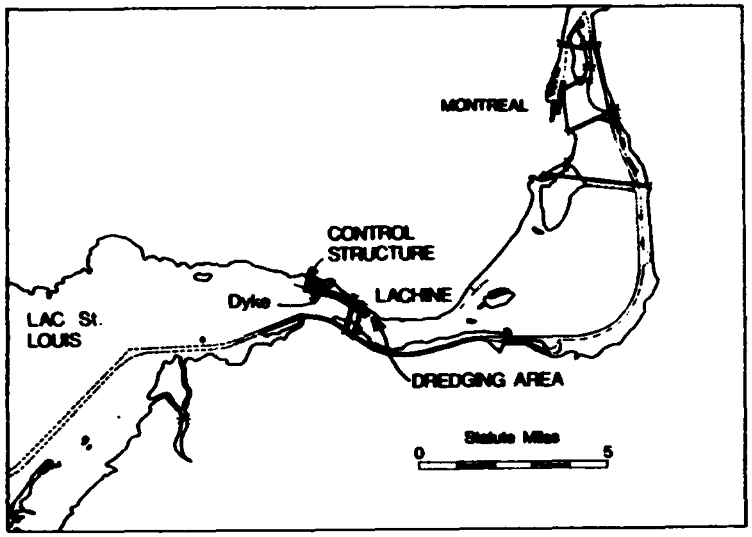
Amounts of Excavation in the Canadian Reach of the St. Lawrence River vs. Increases in River Capacities

FIGURE B-50

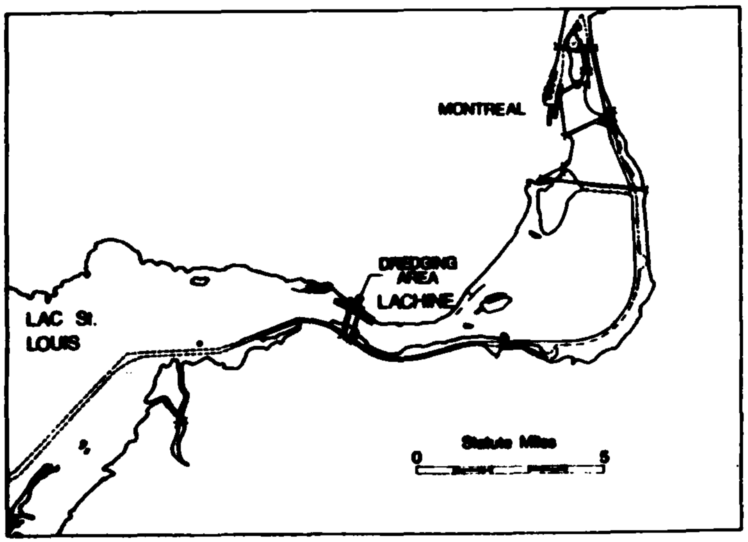
Alternative Remedial Works At Lachine Rapids



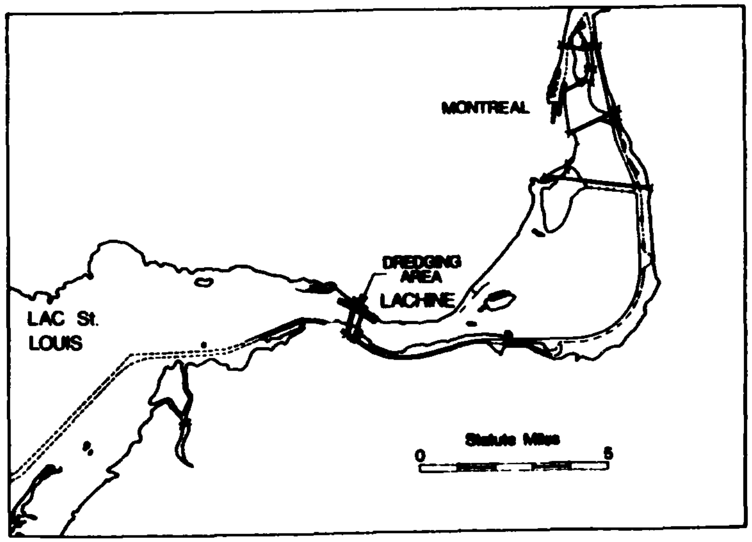
50,000 cfs Alternative 1



35,000 cfs Alternative 2



20,000 cfs Alternative 3



15,000 cfs Alternative 4

FIGURE B - 51

total estimated first cost. To this was added interest during construction calculated by applying interest at 8-1/2 per cent for one-half the estimated construction period to obtain the total investment cost. For capacity increases of 50,000 cfs and 35,000 cfs, this was considered as 3 years. For capacity increases of 20,000 cfs and 15,000 cfs, this was considered 2 years.

Annual cost includes all annual costs occurring after activation of a project and is the sum of the finance costs and operation and maintenance costs.

The method used to estimate each of these factors is described below:

1. Finance costs were calculated on an economic project life of 50 years and include interest and amortization. The annual payments provide for payment of interest and a sinking fund to retire the debt in the timeframe of 50 years. An interest rate of 8-1/2 percent was used.

2. Operation and maintenance costs were estimated by applying percentage factors to the direct cost of the items. Operation and maintenance costs include interim replacement costs, administration, and general expense. Interim replacement costs, when required, were computed on those items which would normally be considered as replaceable before the end of the project life. Replaceable equipment and facilities include gates, gate hoists, stoplogs, and appurtenances. Because of minimum maintenance expected in the excavation channel, a factor of 0.26 percent was used for excavation only with Alternatives 3 and 4. When interim replacements were required with Alternatives 1 and 2, a factor of 0.28 percent was used.

Present worth for each of the excavation alternatives was also calculated in a similar manner as that described in Section 3.5.2,

As stated above, a capacity increase of 15,000 cfs (Alternative 4) would satisfy the IJC requirements for the regulation of Lake Ontario as well as limited regulation of Lake Erie under Plans 6L, 15S, or 25N. This increase would also accommodate the adjusted basis-of-comparison. The cost estimate for this increase is shown in Table B-8.

3.6 Remedial Works Required for Selected Regulation Plans

As previously stated in Section 3.5, excavation would be required in both the International and Canadian Reaches of the St. Lawrence River to accommodate a combined Lakes Erie and Ontario Regulation Plan. The following is a summary of the discharge capacities and costs of these remedial works.

In order to accommodate the adjusted basis-of-comparison or Plan 6L, an additional capacity of 4,000 cfs in the International Reach of the St. Lawrence River would be required. The first cost of the excavation is about \$30.0 million. The corresponding annual cost, after adjustment for finance, and operation and maintenance, is about \$2.9 million. Discharge capacities and a cost summary, including first costs, annual costs, and present worth, are shown in Table B-8.

Plan 15S would require an additional capacity of 6,000 cfs in the International Reach of the St. Lawrence River. The first cost of the excavation is about $45.0 million. The corresponding annual cost, after adjustment for finance, and operation and maintenance, is about $4.3 million. Discharge capacities and a cost summary, including first costs, annual costs, and present worth, are shown in Table B-8.

Plan 25N would require an additional capacity of 5,000 cfs in the International Reach of the St. Lawrence River. The first cost of the excavation is about $38.0 million. The corresponding annual cost, after adjustment for finance, and operation and maintenance, is about $3.4 million. Discharge capacities and a cost summary, including first costs, annual costs, and present worth, are shown in Table B-8.

At the Lachine Rapids area, west of Montreal, all three Lake Erie regulation plans under Category 3 would require an additional capacity of about 15,000 cfs. The first cost of the excavation is about $42.0 million. The corresponding annual cost, after adjustments for finance, and operation and maintenance costs, is estimated to be about $4.0 million. Discharge capacities and a cost summary, including first cost, annual cost, and present worth, are shown in Table B-8.

The following is a summary of the relative discharge capacities and combined costs of remedial works in the International and Canadian Reaches of the St. Lawrence River. The total first costs, based on July 1979 price levels, are $72 million for the adjusted basis-of-comparison and Plan 6L, $87 million for Plan 15S, and $80 million for Plan 25N. The corresponding annual costs are $6.9 million for the adjusted basis-of-comparison and Plan 6L, $8.3 million for Plan 15S, and $7.4 million for Plan 25N. Table B-8 provides a cost summary of remedial works in the St. Lawrence River.

Tables B-9, B-10, B-11, and B-12 show a time profile of all undiscounted and discounted project costs in each year of occurrence over the assumed 50-year economic project life of each of the limited regulation of Lake Erie plans and the adjusted basis-of-comparison.

Table B-9 - Regulation Plan 6L and the Adjusted Basis-of-Comparison - Project Cost Time Profile for International Reach of the St. Lawrence River

Item	Year	Undiscounted Project Cost[1]	Discounted Project Cost[1]
		$	$
Investment Cost		$32,600,000	$32,600,000
Operation and Maintenance Cost	1	80,000	73,733
			67,956
			62,633
			57,726
Operation and Maintenance Cost	5	80,000	53,204
			49,036
			45,194
			41,654
			38,390
Operation and Maintenance Cost	10	80,000	35,383
			32,611
			30,056
			27,702
			25,531
Operation and Maintenance Cost	15	80,000	23,531
			21,688
			19,989
			18,423
			16,980
Operation and Maintenance Cost	20	80,000	15,649
			14,423
			13,293
			12,252
			11,292
Operation and Maintenance Cost	25	80,000	10,408
			9,592
			8,841
			8,148
			7,510
Operation and Maintenance Cost	30	80,000	6,921
			6,379
			5,879
			5,419
			4,994
Operation and Maintenance Cost	35	80,000	4,603
			4,242
			3,910
			3,604
			3,321
Operation and Maintenance Cost	40	80,000	3,061
			2,821
			2,600
			2,397
			2,209
Operation and Maintenance Cost	45	80,000	2,036
			1,876
			1,729
			1,594
			1,469
Operation and Maintenance Cost	50	80,000	1,354
Present Worth			$33,525,246

1/ Cost estimates are based on July 1979 price level, 50-year economic project life and an 8-1/2 percent interest rate.

Table B-10 - Regulation Plan 15S - Project Cost Time Profile for International Reach of the St. Lawrence River

Item	Year	Undiscounted Project Cost[1]	Discounted Project Cost[1]
		$	$
Investment Cost		$48,800,000	$48,800,000
Operation and Maintenance Cost	1	120,000	110,599
			101,935
			93,949
			86,589
Operation and Maintenance Cost	5	120,000	79,805
			73,553
			67,791
			62,480
			57,586
Operation and Maintenance Cost	10	120,000	53,074
			48,916
			45,084
			41,552
			38,297
Operation and Maintenance Cost	15	120,000	35,297
			32,532
			29,983
			27,634
			25,469
Operation and Maintenance Cost	20	120,000	23,474
			21,635
			19,940
			18,378
			16,938
Operation and Maintenance Cost	25	120,000	15,611
			14,3[illegible]
			13,261
			12,222
			11,265
Operation and Maintenance Cost	30	120,000	10,382
			9,569
			8,819
			8,128
			7,492
Operation and Maintenance Cost	35	120,000	6,905
			6,364
			5,865
			5,406
			4,982
Operation and Maintenance Cost	40	120,000	4,592
			4,232
			3,901
			3,595
			3,313
Operation and Maintenance Cost	45	120,000	3,054
			2,815
			2,594
			2,391
			2,204
Operation and Maintenance Cost	50	120,000	2,031
Present Worth			$50,187,871

1/ Cost estimates are based on July 1979 price level, 50-year economic project life and an 8-1/2 percent interest rate.

Table B-11 - Regulation Plan 25N - Project Cost Time Profile for International Reach of the St. Lawrence River

Item	Year	Undiscounted Project Cost[1/]	Discounted Project Cost[1/]
		$	$
Investment Cost		$38,000,000	$38,000,000
Operation and Maintenance Cost	1	100,000	92,166
			84,946
			78,291
			72,157
Operation and Maintenance Cost	5	100,000	66,505
			61,295
			56,493
			52,067
			47,988
Operation and Maintenance Cost	10	100,000	44,229
			40,764
			37,570
			34,627
			31,914
Operation and Maintenance Cost	15	100,000	29,414
			27,110
			24,986
			23,028
			21,224
Operation and Maintenance Cost	20	100,000	19,562
			18,029
			16,617
			15,315
			14,115
Operation and Maintenance Cost	25	100,000	13,009
			11,990
			11,051
			10,185
			9,387
Operation and Maintenance Cost	30	100,000	8,652
			7,974
			7,349
			6,774
			6,243
Operation and Maintenance Cost	35	100,000	5,754
			5,303
			4,888
			4,505
			4,152
Operation and Maintenance Cost	40	100 000	3,827
			3,527
			3,251
			2,996
			2,761
Operation and Maintenance Cost	45	100,000	2,545
			2,345
			2,162
			1,992
			1,836
Operation and Maintenance Cost	50	100,000	1,692
Present Worth			$39,156,562

1/ Cost estimates are based on July 1979 price level, 50-year economic project life and an 8-1/2 percent interest rate.

Table B-12 - Regulation Plans 6L, 15S, and 25N and the Adjusted Basis-of-Comparison - Project Cost Time Profile for Canadian Reach of the St. Lawrence River

Item	Year	Undiscounted Project Cost 1/	Discounted Project Cost 1/
		$	$
Investment Cost		$45,480,000	$45,480,000
Operation and Maintenance Cost	1	90,000	82,949
			76,451
			70,462
			64,942
Operation and Maintenance Cost	5	90,000	59,854
			55,165
			50,843
			46,860
			43,189
Operation and Maintenance Cost	10	90,000	39,806
			36,687
			33,813
			31,164
			28,723
Operation and Maintenance Cost	15	90,000	26,473
			24,399
			22,487
			20,726
			19,102
Operation and Maintenance Cost	20	90,000	17,605
			16,226
			14,955
			13,783
			12,704
Operation and Maintenance Cost	25	90,000	11,708
			10,791
			9,946
			9,167
			8,449
Operation and Maintenance Cost	30	90,000	7,787
			7,177
			6,614
			6,096
			5,619
Operation and Maintenance Cost	35	90,000	5,178
			4,773
			4,399
			4,054
			3,737
Operation and Maintenance Cost	40	90 000	3,444
			3,174
			2,925
			2,696
			2,485
Operation and Maintenance Cost	45	90,000	2,290
			2,111
			1,946
			1,793
			1,653
Operation and Maintenance Cost	50	90,000	1,523
Present Worth			$46,520,900

1/ Cost estimates are based on July 1979 price level, 50-year economic project life and an 8-1/2 percent interest rate.

Section 4

COST SUMMARY OF REGULATORY AND REMEDIAL WORKS

4.1 General

Limited regulation of Lake Erie would require construction of regulatory works at the head of the Niagara River. To implement a combined Lake Erie and Ontario Regulation Plan, remedial works in the St. Lawrence River would also be required. The nature and extent of these works depend on the regulation plan selected.

Table B-13 is a summary of the costs of regulatory and remedial works relative to the regulation plan investigated. These are the preliminary estimates only and not based on detailed design studies.

The costs shown for the St. Lawrence remedial works also reflect those which would be required for channel enlargement to accommodate the high water supplies of the 1970's while not violating the IJC criteria for the regulation of Lake Ontario.

Table B-13 - Summary of Costs of Regulatory and Remedial Works

Regulation Plan	Cost Estimates 1/ (millions of dollars) First Costs	Average Annual Costs	Present Worth
	$	$	$
Plan 6L			
Niagara River	10.3	1.2	13.8
St. Lawrence River			
Internatioanl Reach	30.0	2.9	33.6
Canadian Reach	41.9	4.0	46.5
Total Cost	82.2	8.1	93.9
Plan 15S			
Niagara River	19.6	2.0	22.5
St. Lawrence River			
International Reach	45.0	4.3	50.2
Canadian Reach	41.9	4.0	46.5
Total Cost	106.5	10.3	119.2
Plan 25N			
Niagara River	111.4	11.6	134.3
St. Lawrence River			
International Reach	38.0	3.4	39.1
Canadian Reach	41.9	4.0	46.5
Total Cost	191.3	19.0	219.9
Adjusted Basis-of-Comparison			
St. Lawrence River			
International Reach	30.0	2.9	33.6
Canadian Reach	41.9	4.0	46.5
Total Cost	71.9	6.9	80.1

1/ Cost estimates are based on July 1979 price levels, a 50-year economic life, and an 8-1/2 percent interest rate.

ANNEX A

CONVERSION FACTORS

(BRITISH TO METRIC UNITS)

1 cubic foot per second (cfs) = 0.028317 cubic metres per second (cms)

1 cfs-months = 0.028317 cms-months

1 foot = 0.30480 metres

1 inch = 2.54 centimetres

1 mile (statute) = 1.6093 kilometres

1 ton (short) = 907.18 kilograms

1 ton (long) = 1016.0 kilograms

1 square mile = 2.5900 square kilometres

1 cubic mile = 4.1682 cubic kilometres

Temperature in Celsius: $°C = (°F - 32) / 1.8$

1 acre - feet = 1233.5 cubic metres

1 gallon (U.S.) = 3.7853 litres

1 gallon (British) = 4.5459 litres

ANNEX B

January 16, 1978

Terms of Reference

Regulatory Works Subcommittee

In accordance with the February 21, 1977 letter to the International Joint Commission from the Governments and the International Joint Commission's Directive to the International Lake Erie Regulation Study Board, dated May 10, 1977, the subcommittee will develop engineering designs and cost estimates of regulatory works in the Niagara River and other remedial structures in the Niagara and St. Lawrence Rivers required to implement proposed Lake Erie regulation plans. In carrying out this task the subcommittee will:

a. Prepare preliminary engineering design and cost estimates for regulatory and remedial works in the Niagara River.

b. Prepare preliminary engineering design and cost estimates for remedial works in the St. Lawrence River.

c. Prepare discharge capacity-cost curves for use in regulation plan development.

d. Prepare detailed engineering design and cost estimates for regulatory and remedial works required for selected regulation plans.

e. Prepare reports on investigations.

f. Assist and prepare information for the Public Participation program.

ANNEX C

MEMBERS AND ASSOCIATES LIST
REGULATORY WORKS SUBCOMMITTEE
(1977 - 1981)

Name	Agency	Period of Service From	Period of Service To
J. Foley 1/	U. S. Army Corps of Engineers	Oct. 1977	Completion
D. Cuthbert 1/	Canadian Dept. of Public Works	Oct. 1977	June 1979
	Canadian Dept. of Environment	June 1979	Completion
A. Hollmer	Power Authority of State of New York	Oct. 1977	Completion
A. Tedrow	NYS Dept. of Environmental Conservation	Oct. 1977	Completion
S. Hung	St. Lawrence Seaway Development Corp.	Oct. 1977	Completion
S. Daly	U. S. Army Corps of Engineers	Oct. 1977	Jan. 1978
A. Ellis	Canadian Dept. of Environment	Oct. 1977	Completion
P. Yee	Canadian Dept. of Environment	Oct. 1977	Completion
J. McGregor	Ontario Hydro	Oct. 1977	Completion
J. Erhart 2/	U. S. Army Corps of Engineers	Oct. 1977	Completion

1/ Chairman, Respective Section
2/ Long-Term Associates

ANNEX D

REFERENCE LIST

International Regulation of Lake Erie, Water Levels Study, Construction Estimate, McPhee, Smith, Rosenstein Engineers P.C., July 1978.

International Regulation of Lake Erie, Water Levels Study, Real Estate and Damages, McPhee, Smith, Rosenstein Engineers P.C., July 1978.

International Lake Erie Regulation Study, Summary Report by Regulatory Works Subcommittee, September 1978.

International Lake Erie Regulation Study, Cost Estimate Summary, U.S. Army Corps of Engineers, Buffalo District, January 1980.

Final Report of the Ad-Hoc Economics Subcommittee, May 1978.

Report on Superior-Erie-Ontario Regulation Plan, SEO-17P, U.S. Army Corps of Engineers, September 1974.

Appendix G - Regulatory Works Appendix, Regulation of Great Lakes Water Levels, A Report by the International Great Lakes Levels Board to the International Joint Commission, December, 1973.

Steady-State Sub-Critical Flow Backwater Model for the Niagara River, U.S. Army Corps of Engineers, Buffalo District. See Annex E for a listing of this computer program.

Upper St. Lawrence Hydraulic Transient Model, NOAA Technical Memorandum ERL GLERL - 24 October 1978.

Report by Federal-Provincial Committee on Flow Regulation, Montreal Region, by Environment Canada and Quebec Department of Natural Resources, October, 1976.

International Lake Erie Regulation Study - Lachine Rapids, St. Lawrence River, a report prepared by Engineering Division, Environment Canada, January, 1979.

Hydrographic and Geotechnical Information on the St. Lawrence River, St. Lawrence Seaway Authority, Cornwall, Ontario, 1978.

Hydrographic and Geotechnical Information on the St. Lawrence River, Ontario Hydro, Toronto, Ontario, 1978.

HEC-2 Water Surface Profiles, Users Manual, Hydrologic Engineering Center, U.S. Army Corps of Engineers, October, 1973.

ANNEX E

INTERNATIONAL LAKE ERIE REGULATION STUDY
RATIONALE FOR THE SELECTION OF N3 AS THE
MOST FAVORABLE NIAGARA RIVER ALTERNATIVE FOR
INCREASING THE OUTFLOW FROM LAKE ERIE

To increase the discharge from Lake Erie, seven alternatives were investigated: modification of the Black Rock Lock (L1), three structures in and around Squaw Island (S1, S2, and S3), and three structures partially obstructing the Niagara River (N1, N2, and N3). The following addresses the last three alternatives mentioned above (N schemes) and out-lines the justification for selecting N3 alternative for concentration of further effort.

The maximum proposed diversion flow of 30,000 cfs would have the greatest impact on the hydraulic parameters when the lowest river flow (200,000 cfs) is considered. The water surface and energy profiles for a 200,000 cfs flow were generated and were considered as the base for existing conditions. To pass 230,000 cfs with the same Lake Erie elevation as that associated with the base case, the river cross-sectional area would have to be increased by dredging. Observing the energy profile of the base flow, the greatest energy loss occurs in the area around the Peace Bridge. Although improving the channel bottom by dredging in any reach will decrease the energy loss and thereby increase the flow; it was determined that dredging in the vicinity of the Peace Bridge was the most efficient location, regardless of which structure location is chosen.

Having increased the capacity of the river, the next investigation involved the location of the partial obstruction. Comparing the impact of the three alternative structures on existing river levels the following was noted:

a. N_1 had the least effect on upstream levels and the greatest effect on downstream levels of all schemes.

b. N_2 had the greatest effect on upstream levels and the least effect on downstream levels of all schemes.

c. N_3 appeared to have the least net effect on existing river levels of the three alternatives.

The cost of the alternative sites was also considered. Cursory cost comparisons indicate that the structures for schemes N1 and N2 would be substantially greater than the cost of N3; N1, because of the required length of the structure; and N2, because of the greater river depth at that location.

One further factor influenced the decision. Location of the structure at any of the three sites would certainly increase the potential for ice problems during the winter and spring. However, it has been observed during past ice runs that large ice floes are often broken up in the vicinity of the Peace

Bridge by high velocity flow and contact with the bridge piers. For this reason, schemes N2 and N3 would probably create fewer ice problems than N1.

Considering the hydraulic and economic aspects, as well as the potential for ice problems, N3 was selected as the most favorable "main channel" site for further study.

ANNEX F

COMPUTER PROGRAM

"Steady-State Subcritical Flow Backwater Model
for the Niagara River"

TABLE OF CONTENTS

```
      PROGRAM NIAGARA(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     UPPER NIAGARA RIVER MATH MODEL - 4313 - 722F3023              090443130010
C     20 MAR 1979
C                                                                        43130020
C     SPECIAL STUDIES SECTION                                            43130030
C     HYDRAULICS BRANCH                                                  43130040
C                                                                        43130050
C     COMPUTER UR CYBER 175
C     CARD FORTRAN REV 4                                                 43130090
C     120 COLUMN PAPER                                                   43130100
C                                                                        43130110
C     INPUT CARDS IN FOLLOWING ORDER                                     43130120
C                                                                        43130130
C     READ 1000 - 1 CARD    NUMBER OF SECTIONS IN CHANNEL                43130140
C       FORMAT     I5     N01  WEST NAVY ISLAND                          43130150
C                  I5     N02  EAST NAVY ISLAND                          43130160
C                  I5     N03  CHIPPEWA CHANNEL                          43130170
C                  I5     N04  TONAWANDA CHANNEL BELOW TONAWANDA ISLAND  43130180
C                  I5     N05  WEST TONAWANDA ISLAND                     43130190
C                  I5     N06  EAST TONAWANDA ISLAND                     43130200
C                  I5     N07  TONAWANDA CHANNEL                         43130210
C                  I5     N08  FRENCHMANS CREEK                          43130220
C                  I5     N09  NOT USED                                  43130230
C                  I5     N010 NOT USED                                  43130240
C                                                                        43130250
C     READ 1001 - 1 CARD    N CHANGE                                     43130260
C       FORMAT     I5     NN1  BLACK CREEK GAGE     SECTION 245          43130270
C                  I5     NN2  BEAVER ISLAND GAGE   SECTION 265          43130280
C                  I5     NN3  LASALLE GAGE         SECTION 306          43130290
C                  I5     NN4  HUNTLEY GAGE         SECTION 354          43130300
C                  I5     NN5  BLACK ROCK GAGE      SECTION 525          43130310
C                  I5     NN6  PEACE BRIDGE GAGE    SECTION 6700         43130320
C                                                                        43130330
C     READ 1050 - DATA CARDS - 50 MAXIMUM - 1 BLANK CARD AT END
C       FORMAT   6XI4    ISTA  SECTION NUMBER                            43130350
C                4XI5    LWDA  AREA                                      43130360
C                5XI5    LWDE  ELEVATION                                 43130370
C                6XI4      IW  WIDTH                                     43130380
C                5XI5      IL  LENGTH                                    43130390
C                8XI2      NN  CHANNEL NUMBER                            43130400
C                                                                        43130500
C     READ 1066 - 1 CARD    ONE COEFFICIENT FOR EACH CHANNEL             43130540
C       FORMAT 5F5.2  AFF KINETICE ENERGY COEFICIENT
C                  I5  ISW3 BALANCE AND INCREMENT BYPASS  0 NO, 1 YES
C
C     READ 1065 - 1 CARD                                                 43130510
C       FORMAT14F5.4      AN  ROUGHNESS COEFFICIENT                      43130520
C                                                                        43130560
C     READ 1063 - 1 CARD - FLOW LOSS - SQUAW ISLAND
C       FORMAT     I5     NQL  SECTION NUMBER OF FLOW LOSS
C                 I10     IQL  FLOW LOSS
C                              IF NO FLOW LOSS SET NQL AND IQL TO ZERO
C                                                                        43130410
C     READ 7400 - 1 CARD    TOTAL FLOW AND CONTINUATION CARD
C       FORMAT F10.0       Q  TOTAL FLOW
C       FORMAT   I10       M  NEW DATA , NEW PARAMETER CARD , END OF RUN
C     FOR NEW DATA                     GO TO 1         LET M = 1
C     FOR NEW PARAMETER CARD           GO TO 165       LET M = 2
C     FOR END OF RUN                   GO TO 901       LET M = 3
C                                                                        43130620
C                                                                        43130630
C
C
      DIMENSION ISTA(50,5),LWDA(50,5),LWDE(50,5),IW(50,5),IL(50,5)
      DIMENSION AN(14),AAN(14),AK(10),Q(9),TWS(50,5),A(50,5),AFF(5)
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      DIMENSION ZAN(14)
C      ORIGINAL
    1 L = 1
      KA = 1
      KB = 1
      JX = 1
      JY = 1
      KZ = 2
C
C     READ PARAMETER CARD FOR NUMBER OF SECTIONS IN CHANNEL
C
      READ 1000,NO1,NO2,NO3,NO4,NO5,NO6,NO7,NO8,NO9,NO10
C
C     READ PARAMETER CARD FOR NUMBER OF SECTIONS FOR ROUGHNESS
C     COEFFICIENT CHANGE
C
      READ 1001,NN1,NN2,NN3,NN4,NN5,NN6
   15 GO TO (20,22,24,26,28),L
C
C     READ WEST NAVY ISLAND CHANNEL DATA
C
   20 PRINT 1005
      PRINT 1020
      LL=NO1
      GO TO 49
C
C     READ CHIPPAWA CHANNEL DATA
C
   22 PRINT 1022
      LL= NO3
      GO TO 49
C
C     READ TONAWANDA CHANNEL DATA
C
   24 PRINT 1005
      PRINT 1024
      LL=NO7
      GO TO 49
C
C     READ EAST TONAWANDA ISLAND CHANNEL DATA
C
   26 PRINT 1026
      LL=NO6
      GO TO 49
C
C     READ FRENCHMANS CREEK TO BUFFALO DATA
C
   28 PRINT 1005
      PRINT 1029
      LL=NO8
C
C     READ DATA CARDS
C
   49 K=1
   50 READ 1050,ISTA(K,L),LWDA(K,L),LWDE(K,L),IW(K,L),IL(K,L),NN
C
C     DATA CARD TESTS
C
      IF(IW(K,L).EQ.0)GO TO 120
      N=NN
      IF(N.EQ.L)GO TO 110
      PRINT 1055,L,N
      CALL EXIT
  110 K = K + 1
      GO TO 50
C
```

```
C     PRINT BASIC DATA TABLE                                           43131320
C                                                                      43131330
  120 PRINT 1045                                                       43131340
      DO 160 I = 1,LL
      BLADE=LADE(I,L)
  160 PRINT 1060,ISTA(I,L),LMDA(I,L),BLADE,IN(I,L),IL(I,L),V
      L=L+1
      IF(L.LT.6)GO TO 15
C                                                                      43131390
C     READ PARAMETER CARDS                                             43131400
C                                                                      43131410
      READ 1066,(AFF(I),I=1,5),ISW3
      READ 1065, (ZAN(I),I=1,19)
      READ 1063, V3L,IQL
  165 READ 7400, Q(8),W
      DO 18 IYZ=1,19
      AN(IYZ)=ZAN(IYZ)
   18 CONTINUE
      KA = 1
      KB = 1
      JX = 1
      JY = 1
      KZ = 2
C
      Q(1)=.36*Q(8)
      Q(3)=.6*Q(8)
      Q(5)=Q(1)
C     SLATER'S POINT ELEV COMPUTATION (AS A FUNCTION
C     OF THE TOTAL DISCHARGE, Q(8))
C
      ZMD=561.
      QZ=Q(8)/1000.
      SLPT=56.67933+0.00377*QZ+0.99912*ZMD
      INS(1,1)=INS(1,2)=INS(1,3)=SLPT*100.
      QFLOW=INS(1,1)/100.
C
C                                                                      43131550
C     PRINT PARAMETER CARD TABLE                                       43131560
C                                                                      43131570
      PRINT 1067                                                       43131580
      PRINT 1102                                                       43131590
      PRINT 910
      PRINT 1200,VD1
      PRINT 1201,VD2
      PRINT 1202,VD3
      PRINT 1203,VD4
      PRINT 1204,VD5
      PRINT 1205, VD6
      PRINT 1206, VD7
      PRINT 1207, VD9
      PRINT 900                                                        43131610
      PRINT 911
      PRINT 1208,VV1,ISTA(VV1,2)
      PRINT 1209,VV2,ISTA(VV2,2)
      PRINT 1208,VV3,ISTA(VV3,3)
      PRINT 1209,VV4,ISTA(VV4,3)
      PRINT 1208,VV5,ISTA(VV5,5)
      PRINT 1209,VV6,ISTA(VV6,5)
      PRINT 900                                                        43131630
      PRINT 912
      PRINT 1209,V3L
      PRINT 1210,IQL
      PRINT 900
      PRINT 1213,Q(8)
      PRINT 1214,Q(3)
      PRINT 1215,Q(1)
```

```
      PRINT 1216,Q(5)
      PRINT 900                                                         43131650
      PRINT 1217, QFLOW
      PRINT 900
      PRINT 913
      DO 10 IT=1,14
      PRINT 1211,IT,AN(IT)
   10 CONTINUE
      PRINT 900                                                         43131670
      PRINT 914
      DO 11 LT=1,5
      PRINT 1212,LT,AFF(LT)
   11 CONTINUE
      PRINT 915,M
      PRINT 901                                                         43131690
C
C                                                                       43131700
C     FOR ROUGHNESS COEFFICIENT                                         43131710
      DO 162 I = 1,14
  162 AAN(I) = AN(I)
  163 DO 164 I = 1,14
  164 AK(I) = AN(I) * AN(I)
C                                                                       43131760
C     WEST NAVY ISLAND CHANNEL                                          43131770
C                                                                       43131790
      POW=4./3.
      QC=Q(1)
C                                                                       43131810
C     FOR PRINT OUT OF BACKWATER COMPUTATIONS SENSE SWITCH 3 ON         43131820
C     IF SENSE SWITCH 3 ON BALANCE AND INCREMENT WILL NOT OCCUR         43131830
C                                                                       43131840
      IF(ISW3-1.NE.0)GO TO 167
      KZ=1
  167 IF(KZ.EQ.2)GO TO 169
      PRINT 1067
      PRINT 1020                                                        43131890
      PRINT 1069                                                        43131900
  169 L = 0
      LA = 0
      I = 1
  170 L = L + 1
      LA = LA + 1
      A(I,L) = LWDA(I,L)+((IWS(I,L)-LWDE(I,L))/100.)*IW(I,L)
      VDN=Q(LA)/A(I,L)
      HVDN=VDN*VDN*AFF(L)*.0155473
  173 IF(KZ.EQ.2)GO TO 180
      VHEAD=VDN*VDN/(2.*32.2)
      RIWS=IWS(I,L)
      THEAD=RIWS/100.+VHEAD
      PRINT 1310,ISTA(I,L),RIWS,Q(LA),A(I,L),IW(I,L),VDN,VHEAD,THEAD
  180 J = I +1
      IWS(J,L) = IWS(I,L) + 2
      KJ=IJ=IJJ=1
  190 IELEV = IWS(J,L)
      A(J,L) = LWDA(J,L) + ((IWS(J,L) - LWDE(J,L))/100.) * IW(J,L)
      VUP=Q(LA)/A(J,L)
      HVUP=VUP*VUP*AFF(L)*.0155473
      HV=HVDN-HVUP
C                                                                       43132090
      TANT=((IW(I,L) -IW(J,L)) *.5) /IL(I,L)
C     TEST FOR WELL-DESIGNED TRANSITION                                 43132100
C                                                                       43132110
      TANA  = ((  A (I,L) /IW(I,L)) -(   A (J,L) /IW(J,L)))/IL(I,L)
      DEVT = .22169 - ABS(TANT)
      DEVA = .22169 - ABS(TANA)
      IF(DEVA.LE.0.)GO TO 197
```

```
      IF(DEVI.LE.0.)GO TO 197
      CC=.1
      CE=.2
      GO TO 198                                                         43132200
  197 CC=.25
      CE=.5
C                                                                       43132240
  198 IF(HV)200,220,210
  200 HT=-CE*HV
      COEF = CE
      GO TO 230                                                         43132290
  210 HT =  CC*HV
      COEF = CC
      GO TO 230                                                         43132310
  220 HT = 0.
      COEF = 0.
  230 AAVE=.5*(A(I,L)+A(J,L))
      WAVE = .5*(IW(I,L) + IW(J,L))
      R=AAVE/WAVE
      HFR=QC*QC*IL(I,L)*AK(L)/(2.2082*AAVE*AAVE*R**POW)
      HTOTAL=HV+HT+HFR
      IH = HTOTAL * 100
      IF((HTOTAL*1000-IH*10-5).GE.0.)GO TO 234
      HTOTAL=IH
      GO TO 235                                                         43132420
  234 HTOTAL = IH + 1
  235 CONTINUE                                                          43132440
      IWS(J,L) = IWS(I,L) + HTOTAL
      IX = IWS(J,L)
      IF(IX-IELEV)260,270,263
  260 IF(KJ.GE.2)GO TO 262
      KJ=IJ=2
      GO TO 190                                                         43132520
  262 IF(IJ-2)270,190,190
  263 IF(KJ.GE.2)GO TO 265
      KJ=IJJ=2
      GO TO 190                                                         43132560
  265 IF(IJJ.GE.2)GO TO 190
  270 IF(KZ.EQ.2)GO TO 290
      IWAVE=WAVE
      VHEAD=VUP*VUP/(2.*32.2)
      RIWS=IWS(J,L)
      THEAD=RIWS/100.+VHEAD
      PRINT 1080,QC,AAVE,IWAVE,R,IL(I,L),AN(L),HV,HT,HFR,HTOTAL,COEF
      PRINT 1310,ISTA(J,L),RIWS,Q(LA),A(J,L),IW(J,L),VUP,VHEAD,THEAD
  290 I=J
      VDN=VUP
      HVDN = HVUP
      GO TO (330,370,420,450,521,541,560,750),LA
C                                                                       43132650
C     EAST NAVY ISLAND CHANNEL                                          43132660
C                                                                       43132670
C     SECTION COUNTER , WEST NAVY ISLAND                                43132680
  330 IF(I.LT.ND1)GO TO 190
      IF(KZ.EQ.2)GO TO 344
      PRINT 1090,L,AFF(L)
  344 L = 1
      I = 1
      QC = Q(2) = Q(3) - Q(1)
      IF(KZ.EQ.2)GO TO 360
      PRINT 1021
      PRINT 1069                                                        43132770
  360 GO TO 170                                                         43132780
C
C     SECTION COUNTER , EAST NAVY ISLAND                                43132790
C
```

```
  370 IF(I.LT.NO2)GO TO 190
      IF(KZ.EQ.2)GO TO 390
      PRINT 1090,L,AFF(L)
C                                                                       43132830
C     BALANCE NAVY ISLAND                                               43132840
C                                                                       43132850
  380 IF(KZ.EQ.1)GO TO 410
      PRINT 6000, INS(NO1,1), INS(NO2,2), Q(1), Q(2), KA, JX
      IF(KA.EQ.5)GO TO 402
      CALL BALANCE (N1,N2,Q1,INS(NO1,1),INS(NO2,2),Q(1),Q(1),KA)
      IF(Q(1).LE.0.)GO TO 401
      IF(Q(2).LE.0.)GO TO 401
      IF (KA-4) 405,403,403
  401 KA = 1
      PRINT 1103                                                        43132940
      GO TO 405                                                         43132950
  402 CALL INCREM(IO1,INS(NO1,1),INS(NO2,2),Q(1),KA,JX)
      IF(KA.LT.4)GO TO 405
  403 KA=1
      JX = 1
      GO TO 410                                                         43133000
  405 I=1
      QC=Q(1)
      Q(2) = Q(3) - Q(1)
      GO TO 169                                                         43133040
C                                                                       43133050
C       CHIPPAWA CHANNEL ABOVE NAVY ISLAND                              43133060
C                                                                       43133070
  410 IF(KZ.EQ.2)GO TO 414
      PRINT 1067
      PRINT 1030                                                        43133100
      PRINT 1069                                                        43133110
  414 I = NO2 + 1
      INS(I,2) = INS(NO1,1)
      L=1
      AN(2) = AN(3)
      AK(2) = AK(3)
      QC = Q(3)
      NN1 = NO2 + 15
      GO TO 170                                                         43133190
C
C     N CHANGE ,  BLACK CREEK GAGE                                      43133200
C
  420 IF (J - NN1) 440,422,424
  422 AN(2) = AN(4)
      AK(2) = AK(4)
      GO TO 180                                                         43133240
C
C     N CHANGE, BEAVER ISLAND GAGE                                      43133250
C
  424 IF (I - NN2) 440,426,430
  426 AN(2) = AN(5)
      AK(2) = AK(5)
      GO TO 180                                                         43133290
C
C     PAGE CHANGE                                                       43133300
C
  430 IF(J.NE.NN1)GO TO 440
      IF(NO3.LE.NN1)GO TO 440
      IF(KZ.EQ.2)GO TO 173
      PRINT 1067
      PRINT 1030                                                        43133350
      PRINT 1069                                                        43133360
      GO TO 173                                                         43133370
C
C     SECTION COUNTER , CHIPPEWA CHANNEL                                43133390
```

```
C
  440 IF(I.LT.N03)GO TO 190
C
C     TONAWANDA CHANNEL BELOW TONAWANDA ISLAND
C
      IF(KZ.EQ.2)GO TO 454
      PRINT 1090, L, AFF(L)
      PRINT 1067
      PRINT 1023
      PRINT 1069
  454 I=1
      AN(3) = AN(6)
      AK(3) = AK(6)
      QC = Q(4) + Q(7) + Q(8) - Q(3)
      GO TO 170
C
C     N CHANGE, LASALLE GAGE
C
  460 IF (J - NN3) 470,462,463
  462 AN(3) = AN(7)
      AK(3) = AK(7)
      GO TO 190
C
C     PAGE CHANGE
C
  463 IF (J.NE.19)GO TO 470
      IF(N04.LE.19)GO TO 470
      IF(KZ.EQ.2)GO TO 173
      PRINT 1067
      PRINT 1069
      PRINT 1023
      GO TO 173
C
C     SECTION COUNTER , TONAWANDA CHANNEL BELOW TONAWANDA ISLAND
C
  470 IF(I.LT.N04)GO TO 190
C
C     WEST TONAWANDA ISLAND CHANNEL
C
      IF(KZ.EQ.2)GO TO 520
      PRINT 1090, L, AFF(L)
      PRINT 1067
      PRINT 1026
      PRINT 1069
  520 I = N04 + 1
      L=2
      INS(I,3) = INS(N04,3)
      AN(3) = AN(8)
      AK(3) = AK(8)
      QC = Q(5)
      GO TO 170
C
C     SECTION COUNTER , WEST TONAWANDA ISLAND
C
  521 IF(I.LT.N05)GO TO 190
C
C     EAST TONAWANDA ISLAND CHANNEL
C
      IF(KZ.EQ.2)GO TO 570
      PRINT 1090, L, AFF(L)
  570 I=1
      INS(1,4) = INS(N04,3)
      AN(4) = AN(9)
      AK(4) = AK(9)
      QC = Q(6) + Q(8) - Q(5)
      IF(KZ.EQ.2)GO TO 173
```

```
      PRINT 1027
      PRINT 1068                                                    43133970
      GO TO 170                                                     43133980
C
C     SECTION COUNTER , EAST TONAWANDA ISLAND
  571 IF(I.LT.NO6)GO TO 190
      IF(KZ.EQ.2)GO TO 600
      PRINT 1090, LW AFF(LU)
C                                                                   43134030
C     BALANCE TONAWANDA ISLAND                                      43134040
C                                                                   43134050
  600 IF(KZ.EQ.1)GO TO 650
      PRINT 6001, IWS(NO5,3), IWS(NO6,4), Q(3), Q(6), KA, JX
      IF(KA.EQ.3)GO TO 610
      CALL BALANCE(W5,W6,D3,IWS(NO5,3),IWS(NO6,4),Q(5),Q(5),KA)
      IF(Q(5).LE.0.)GO TO 609
      IF(Q(6).LE.0.)GO TO 609
      IF (KA - 4) 614,612,612
  609 KA = 1
      PRINT 1103                                                    43134140
      GO TO 614                                                     43134150
  610 CALL INCREM(ID2,IWS(NO5,3),IWS(NO6,4),Q(5),KA,JX)
      IF(KA.LT.4)GO TO 614
  612 KA=1
      JX = 1
      GO TO 650                                                     43134200
  614 I = NO4 + 1
      L = 2
      LA = LA - 2
      QC = Q(5)
      Q(6) = Q(4) - Q(5)
      GO TO 170                                                     43134260
C                                                                   43134270
C     TONAWANDA CHANNEL ABOVE TONAWANDA ISLAND                      43134280
C                                                                   43134290
  650 IF(KZ.EQ.2)GO TO 654
      PRINT 1067
      PRINT 1025                                                    43134320
  654 I = NO5 + 1
      IWS(I,3)=IWS(NO5,3)
      AN(3)=AN(10)
      AK(3)=AK(10)
      L=2
      QC=Q(7)
      MM2=NO5+14
      GO TO 170
C
C     PAGE CHANGE                                                   43134420
C
  660 IF(J.NE.MM2)GO TO 670
      IF(KZ.EQ.2)GO TO 173
      PRINT 1067
      PRINT 1025                                                    43134460
      PRINT 1069                                                    43134470
      GO TO 173                                                     43134480
C
C     N CHANGE , HUNTLEY                                            43134490
C
  670 IF(J.NE.NN4)GO TO 690
      AN(3)=AN(11)
      AK(3)=AK(11)
      GO TO 180                                                     43134530
C
C     SECTION COUNTER , TONAWANDA CHANNEL ABOVE TONAWANDA ISLAND    43134580
C
  680 IF(I.LT.NO7)GO TO 190
```

```
      IF(KZ.EQ.2)GO TO 700
      PRINT 1090,L,AFF(L)
C                                                                       43134580
C     BALANCE GRAND ISLAND                                              43134590
C                                                                       43134600
  700 IF(KZ.EQ.1)GO TO 750
      DEV=(INS(ND3,2)-INS(ND7,3))
      IDEV=DEV
      PRINT 6002,INS(ND3,2),INS(ND7,3),Q(3),Q(7),KB,JY,IDEV
      IF(KB.EQ.3)GO TO 710
      CALL BALANCE(N3,N7,D2,INS(ND3,2),INS(ND7,3),Q(3),Q(3),KB)
      IF(Q(3).LE.0.)GO TO 709
      IF(Q(7).LE.0.)GO TO 709
      IF(KB-4)714,712,712
  709 KB=1
      PRINT 1103                                                        43134700
      GO TO 714                                                         43134710
  710 CALL INCREM(ID3,INS(ND3,2),INS(ND7,3),Q(3),KB,JY)
      IF(KB.LT.4)GO TO 714
  712 KA=1
      KB=1
      JX=1
      JY=1
      KZ=1
      DO 713 I=1,14
  713 AN(I)=AAN(I)
      PRINT 1104
      GO TO 143
  714 QC=Q(1)=Q(5)-Q(2)
      Q(4)=Q(7)=Q(9)-Q(5)
      DO 715 I=1,14
  715 AN(I)=AAN(I)
      DO 716 I=1,14
  716 AK(I)=AN(I)+AN(I)
      GO TO 169
C                                                                       43134950
C     FRENCHMANS CREEK TO BUFFALO                                       43134960
C                                                                       43134970
  750 PRINT 1067                                                        43134980
      PRINT 1024                                                        43134990
      PRINT 1069                                                        43135000
      I=1
      L=4
      INS(1,5)=INS(ND7,3)
      AN(5)=AN(12)
      AK(5)=AK(12)
      QC=Q(8)
      GO TO 170                                                         43135070
C
C     N CHANGE , BLACK ROCK                                             43135080
C
  760 IF(J-NN5)768,762,770
  768 IF(NQL.LE.0)GO TO 790
      IF(IQL.LE.0)GO TO 790
      IF(ISTA(J,L)-NQL)790,769,767
  769 QC=Q(LA)-IQL/2
      Q(LA)=Q(LA)-IQL
      NNA=1
      GO TO 790
  767 IF(NNA.EQ.2)GO TO 790
      QC=Q(LA)
      NNA=2
      GO TO 790
  762 AN(5)=AN(13)
      AK(5)=AK(13)
      IF(NQL.LE.0)GO TO 190
```

```
      IF(IQL.LE.0)GO TO 190
      IF(ISTA(J,L)-NQL)190,764,766
  764 QC=Q(LA)-IQL/2
      Q(LA)=Q(LA)-IQL
      NNA=1
      GO TO 180
  766 IF(NNA.EQ.2)GO TO 190
      QC=Q(LA)
      NNA=2
      GO TO 190
C
C     FLOW LOSS SOJAK ISLAND
C
  770 IF(NQL.LE.0)GO TO 775
      IF(IQL.LE.0)GO TO 775
      IF(ISTA(J,L)-NQL)775,772,774
  772 QC=Q(LA)-IQL/2
      Q(LA)=Q(LA)-IQL
      NNA=1
      GO TO 775
  774 IF(NNA.EQ.2)GO TO 775
      QC=Q(LA)
      NNA=2
C
C     PAGE CHANGE
C
  775 IF(J-14)790,779,790
  779 PRINT 1067
      PRINT 1028
      PRINT 1069
      GO TO 173
C
C     N CHANGE , PEACE BRIDGE
C
  780 IF(I.NE.NN6)GO TO 790
      AN(5)=AN(14)
      AK(5)=AK(14)
      GO TO 180
C
C     SECTION COUNTER , FRENCHMANS CREEK TO BUFFALO
C
  790 IF(I.LT.NOS)GO TO 190
      PRINT 1090,L,AFF(L)
      IF(M-2)1,165,801
  801 CALL EXIT
C
C     FORMAT STATEMENTS
C
  900 FORMAT(1H0)
  901 FORMAT(1H1)
  910 FORMAT(20X,*NUMBER OF SECTIONS IN CHANNEL*,/)
  911 FORMAT(20X,*MANNINGS  N  CHANGES*,/)
  912 FORMAT(20X,*FLOW LOSSES AT SOJAK IS*,/)
  913 FORMAT(20X,*MANNINGS COEFFICIENT*,/)
  914 FORMAT(/,20X,*KINETIC ENERGY COEF*,/)
  915 FORMAT(/,20X,*SUBROUTINE BYPASS (BALANCE AND INCREM) = *,I2)
 1000 FORMAT(10I5)
 1001 FORMAT(6I5)
 1005 FORMAT(1H1,////,40X,15HBASIC DATA TABLE)
 1020 FORMAT(//,36X,20HWEST NAVY ISLAND CHANNEL,//)
 1021 FORMAT(//,35X,20HEAST NAVY ISLAND CHANNEL,//)
 1022 FORMAT(//,40X,16HCHIPPAWA CHANNEL,//)
 1023 FORMAT(//,40X,30HTONAWANDA CHANNEL BELOW TON IS,//)
 1024 FORMAT(//,40X,17HTONAWANDA CHANNEL,//)
 1025 FORMAT(//,40X,30HTONAWANDA CHANNEL ABOVE TON IS,//)
 1026 FORMAT(//,34X,29HWEST TONAWANDA ISLAND CHANNEL,//)
```

```
1027 FORMAT(//,34X,29HEAST TONAWANDA ISLAND CHANNEL,//)
1029 FORMAT(//,35X,27HFRENCHMANS CREEK TO BUFFALO,//)
1030 FORMAT(//,40X,30HCHIPPAWA CHANNEL ABOVE NAVY IS,//)
1045 FORMAT(26X,3HSEC,5X,9HLWD AREA,3X,9HLWD ELEV,5X,5HWIDTH,4X,
    + 6HLENGTH,4X,2HCH,/)
1050 FORMAT(6X,I4,4X,I6,5X,I5,6X,I4,5X,I5,8X,I2)
1055 FORMAT(5X,24HCHANNEL NUMBER INCORRECT,2(5X,I2))
1060 FORMAT(25X,I4,5X,I5,5X,-2PF6.2,5X,I5,5X,I5,9X,I2)
1063 FORMAT(I5,I10)
1064 FORMAT(5F10.0)
1065 FORMAT(14F5.4)
1066 FORMAT(5F5.2,I5)
1067 FORMAT(1H1,/,45X,20HUS ARMY CORPS OF ENG,/,47X,16HDETROIT DISTRICT
    +,//,44X,21HWATER SURFACE PROFILE,/,43X,22HBACKWATER COMPUTATIONS,
    + //)
1068 FORMAT(2X,4HSECT,4X,4HW.S.,6X,1HQ,5X,1HA,6X,1HW,6X,1HR,6X,1HL,
    + 7X,1HN,4X,1HV,6X,2HHV,6X,2HHT,6X,3HHFR,3X,5HTOTAL,2X,4HCOEF,
    + 4X,*VV/2G*,3X,*ENERGY*,
    + 3X,*ANG*,/,
    + 13X,4HELEV,/)
1070 FORMAT(4X,I4,3X,-2PF7.2,2X,0PF7.0,2X,F7.0,2X,I4,23X,F6.3)
1080 FORMAT(17X,F7.0,2X,F7.0,2X,I4,2X,F5.2,3X,I5,2X,F5.4,9X,F5.3,2X,
    + F6.3,2X,F6.3,2X,-2PF5.2,2X,0PF6.2,20X,F4.1)
1090 FORMAT(/,10X,4HAFF(,I1,4H) = ,F5.2)
1100 FORMAT(I1)
1102 FORMAT(//,44X,20HCOMPILED 20 MAR 1974,//,44X,20HPARAMETER CARD TAB
    +LE,/,52X,4H4313,////)
1103 FORMAT(/,70X,13HNEGATIVE FLOW)
1104 FORMAT(//,5X,14HMODEL BALANCED)
1200 FORMAT(21X,*WEST NAVY IS         = *,I5)
1201 FORMAT(21X,*EAST NAVY IS         = *,I5)
1202 FORMAT(21X,*CHIPPAWA CHANNEL     = *,I5)
1203 FORMAT(21X,*TON CH BELOW TON IS = *,I5)
1204 FORMAT(21X,*WEST TONAWANDA IS   = *,I5)
1205 FORMAT(21X,*EAST TONAWANDA IS   = *,I5)
1206 FORMAT(21X,*TON CH ABOVE TON IS = *,I5)
1207 FORMAT(21X,*FRENCHMANS CREEK     = *,I5)
1208 FORMAT(21X,I3,* (SECTION *,I5,*)*)
1209 FORMAT(24X,*SEC NO = *,I4)
1210 FORMAT(24X,*LOSS = *,I5)
1211 FORMAT(23X,I3,2X,F5.4)
1212 FORMAT(21X,*CHANNEL *,I1,* = *,F5.2)
1213 FORMAT(20X,*TOTAL DISCHARGE, CFS = *,F11.0)
1214 FORMAT(20X,*FLOW IN CHIPPAWA CHANNEL = *,F7.0)
1215 FORMAT(20X,*FLOW IN WEST NAVY IS = *,F11.0)
1216 FORMAT(20X,*FLOW IN WEST TON IS = *,F12.0)
1217 FORMAT(20X,*STARTING ELEVATION AT SLATERS POINT = *,F6.2)
1310 FORMAT(1X,I4,3X,-2PF7.2,2X,0PF7.0,2X,F7.0,2X,I4,23X,F6.3,44X,F4.2,
    + 2X,F8.2)
6000 FORMAT(/,5X,15HNAVY IS    WS = ,2I 5,2X,4HQ = ,2F8.0,2X,5HKA = ,
    + I1,2X,5HJK = ,I1)
6001 FORMAT(/,5X,15HTON IS     WS = ,2I 5,2X,4HQ = ,2F8.0,2X,5HKA = ,
    + I1,2X,5HJK = ,I1)
6002 FORMAT(//,5X,15HGRAND IS  WS = ,2I5,2X,4HQ = ,2F8.0,2X,5HKB = ,
    + I1,2X,5HJY = ,I1,2X,5HDEV = ,I5,/)
7400 FORMAT(F10.0,I10)
     END
     SUBROUTINE BALANCE(W1,W2,DDS,IWS3,IWS4,Q3,Q5,K4)
C    SUBROUTINE FOR BALANCING FLOWS IN BACKWATER COMPUTATIONS      090H
C
C    CALL NAME BALANCE
C
C    29 JAN 1969
C
C    CARD FORTRAN REV 4
C    COMPUTER US CYBER 173
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C     PROGRAMMER FRANK H. QUINN
C
C     ARGUMENTS-IWS3,IWS4 - W.S. ELEVATIONS (IN)
C               Q3-Q(IN)
C               QS - Q(OUT)
C               KA-INDEX
C
C     INPUT ELEVATIONS ARE FIXED POINT
C
C
      IF(KA.EQ.2)GO TO 6
      W1=IWS3
      W2=IWS4
      IDFA=IWS3-IWS4
      IF(IDFA.EQ.0)GO TO 7
      QQ3=Q3
      IF(IDFA)3,7,4
    3 QS=Q3+4000.
      GO TO 5
    4 QS=Q3-4000.
    5 KA=2
      GO TO 8
    6 IQ=(QQ3+(W1-W2)*(Q3-QQ3)/(W1-W2-IWS3+IWS4))*.01
      QS=IQ*100.
      KA=3
      GO TO 8
    7 KA=4
    8 RETURN
      END
      SUBROUTINE INCREM(IDFB,IWS3,IWS4,QS,KA,JJ)
C     SUBROUTINE FOR INCREMENTING FLOWS IN BACKWATER COMPUTATIONS   090H0
C
C     CALL NAME INCREMENT
C
C     29 JAN 1969
C     CARD FORTRAN REV 4
C     COMPUTER US CYBER 173
C     PROGRAMMER FRANK H. QUINN
C
C     ARGUMENTS-IWS3,IWS4 - W.S. ELEVATIONS (IN)
C               QS - Q(OUT)
C               KA-INDEX
C
C     INPUT ELEVATIONS ARE FIXED POINT
C
C
      IDFA=IWS4-IWS3
      IF(JJ.EQ.2)GO TO 25
      IDFB=IDFA
   25 IF(IDFA)35,55,30
   30 IF(IDFB)55,55,40
   35 IF(IDFB.GE.0)GO TO 55
   40 JJ=2
      IF(IDFA)45,55,50
   45 QS=QS-100.
      GO TO 60
   50 QS=QS+100.
      GO TO 60
   55 KA = 4
      JJ=1
   60 RETURN
      END
```

4 5 19 13 15 6 33 49 1 1 NO SEC PER CH 4313
11 15 4 29 6 31 SEC NO FOR V CHANGE 4313

100	25400	55070	1700	1300	1		
105	24600	55075	1900	3300	1		
110	24900	55099	1975	2000	1		
115	31500	56076	2350	0	1		
					1		
200	53200	55070	4500	5100	2		
203	20500	55090	1650	2000	2		
205	16100	56099	1700	2700	2		
210	16100	55107	1700	1700	2		
215	17900	55116	1700	0	2		
220	49500	55116	4050	2750	2	11	15
225	42100	55127	2550	3800	2	11	20
230	40900	55142	2900	6200	2	5	25
235	32900	56166	2500	7100	2	20	25
240	46600	55194	2450	3700	2	25	22
245	49500	56209	3750	9000	2	45	50
250	47200	56241	2750	6000	2	35	40
255	45400	55265	2000	2700	2	20	23
260	41900	56275	3500	6200	2	75	3
265	39600	55300	3900	1500	2	17	0
270	33100	55307	2325	1800	2	12	0
275	36500	55316	2650	1700	2	16	0
290	42000	55324	2725	1800	2	14	0
295	55400	55333	3500	0	2	20	0
					2		
300	32600	55070	1885	1950	3		
302	33500	56075	1905	1100	3		
304	39200	55090	3300	2850	3		
306	41120	55099	3600	4500	3		
308	37900	56100	3500	7500	3		
310	36570	55127	2700	8700	3		
312	23900	55200	2700	1900	3		
314	37990	55200	3950	1300	3		
316	35700	55200	3760	1850	3		
318	37270	55200	3350	1000	3		
320	35240	56200	3240	2150	3		
322	34370	55200	2850	2800	3		
324	41010	56200	2900	0000	3		
325	33070	56200	2400	300	3		
326	33070	56200	2400	3900	3		
328	27340	55200	2050	0000	3		
330	37390	55200	2550	3200	3		
332	33010	55200	1500	1400	3		
334	33730	55200	1510	2600	3		
336	35530	55200	1920	2400	3		
338	35950	56200	1780	2200	3		
340	34970	56200	1750	1800	3		
342	35470	55200	1840	2200	3		
344	33550	56200	1700	2000	3		
346	36550	56200	1950	4950	3		
348	39120	56200	1650	1400	3		
350	44470	56200	1920	1700	3		
352	42090	56200	2000	2650	3		
354	29100	55300	1500	1500	3		
356	27100	55307	1400	1500	3		
358	25400	56314	1580	1750	3		
360	24500	56322	1900	2350	3		
342	31700	56334	2325	0	3		
					3		

400	7990	56200	400	200	4		
405	5560	56174	325	3500	4		
410	6220	56205	430	200	4		
415	3000	56206	200	200	4		
420	4390	56206	400	1600	4		
425	8540	56212	600	0	4		
					4		
500	97100	56334	6125	2000	5	1973	COND
505	96700	56343	5400	2700	5	1973	COND
510	88700	56355	3150	1500	5	1973	COND
515	39900	56366	1900	300	5	1973	COND
520	40000	56367	1900	600	5	1973	COND
525	39970	56370	1680	910	5	1973	COND
530	41550	56395	1530	630	5	1973	COND
535	42920	56411	1575	650	5	1973	COND
540	40420	56425	1730	600	5	1973	COND
542	49920	56443	1735	530	5	1973	COND
545	44130	56459	1650	610	5	1973	COND
547	40900	56473	1630	650	5	1973	COND
550	40690	56499	1690	690	5	1973	COND
555	46000	56509	1540	740	5	1973	COND
560	40700	56527	1290	440	5	1973	COND
562	44900	56539	1220	530	5	1973	COND
564	31500	56551	1245	720	5	1973	COND
568	27000	56569	1340	360	5	1973	COND
569	20700	56579	1410	390	5	1973	COND
570	20730	56599	1510	510	5	1973	COND
571	25090	56650	1520	100	5	1973	COND
572	25670	56650	1560	100	5	1973	COND
573	24990	56650	1600	100	5	1973	COND
574	25190	56660	1600	100	5	1973	CON
575	24840	56670	1630	100	5	1973	COND
576	24550	56670	1630	100	5	1973	COND
577	24120	56690	1640	100	5	1973	COND
578	24090	56690	1630	100	5	1973	COND
579	25570	56710	1670	100	5	1973	COND
580	26140	56710	1670	100	5	1973	COND
581	22730	56720	1570	100	5	1973	COND
582	25970	56790	1670	100	5	1973	COND
583	26410	56900	1720	100	5	1973	COND
584	26430	56900	1960	100	5	1973	COND
585	26320	56910	1780	100	5	1973	COND
586	28120	56910	1730	100	5	1973	COND
587	30360	56910	1780	100	5	1973	COND
588	31790	56960	1930	100	5	1973	COND
589	32260	56710	2020	100	5	1973	COND
590	33360	56940	2080	100	5	1973	COND
591	33390	56970	2150	880	5	1973	COND
592	29460	56679	2540	890	5	1973	COND
593	35020	56702	3040	1200	5	1973	COND
595	39200	56733	3170	990	5	1973	COND
600	47690	56764	4935	850	5	1973	COND
605	80310	56795	6180	1190	5	1973	COND
610	93740	56919	7040	1230	5	1973	COND
615	125990	56949	8270	880	5	1973	COND
620	173370	56970	9360	0	5	1973	COND
					5		

116 116 116 115 118 0
277 277 277 233 237 260 260 260 260 225 225 240 240 290
0 0
210000 3

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